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# The use of real-time ultrasound and live animal measurements to predict carcass composition in beef cattle

Scott Patrick Greiner
*Iowa State University*

The use of real-time ultrasound and live animal measurements to predict carcass composition in beef cattle

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Scott Patrick Greiner

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Scott Patrick Greiner

has met the dissertation requirements of Iowa State University

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Committee Member

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Committee Member

Signature was redacted for privacy.

Committee Member

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Committee Member

Signature was redacted for privacy.

Major Professor

Signature was redacted for privacy.

For the Major Program

Signature was redacted for privacy.

For the Graduate College

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## ABSTRACT

Five hundred thirty-four steers representing 6 sire breed groups were evaluated in 1994 (n = 282) and 1995 (n = 252) to determine the efficacy of using real-time ultrasound and other live animal measures to predict beef carcass composition. Within 5 days prior to slaughter, steers were ultrasonically measured for 12-13th rib fat (UFAT), longissimus muscle area (UREA), rump fat thickness (URPFAT), and body wall thickness (UBDWALL). Carcasses were fabricated to determine boneless, totally trimmed retail product weight (KGRPRD) and percentage (PRPRD). Correlation coefficients between UFAT and UREA with carcass 12-13th rib fat (CFAT) and carcass longissimus muscle area (CREA) were .89 and .86, respectively. Mean differences indicated UFAT was .06 cm less ($P < .01$) than CFAT, and UREA was .71 $cm^2$ greater ($P < .01$) than CREA across both years. Carcass measurements were more accurately evaluated with ultrasound in 1994 than in 1995 ($P < .01$). Regression equations to predict KGRPRD and PRPRD were developed using either live animal or carcass traits as independent variables. Final models ($P < .10$) using live animal ultrasound variables included live weight (FWT), UFAT, UREA, and URPFAT for KGRPRD ($R^2 = .84$) and UFAT, URPFAT, UREA, UBDWALL, and FWT for PRPRD ($R^2 = .61$). Comparatively, equations using carcass yield grade variables resulted in $R^2$ values of .86 and .65 for KGRPRD and PRPRD, respectively. When equations developed from 1994 steers were applied to steers in 1995, correlations between values predicted from live animal models and actual carcass values were .92 for KGRPRD, and ranged from

.73 to .76 for PRPRD. Similar correlations were found for equations developed from carcass measurements (r = .94 for KGRPRD and .80 to .81 for PRPRD). Both live animal and carcass equations overestimated ($P < .01$) actual KGRPRD and PRPRD. Regression of predicted values on actual values revealed a similar fit for live animal and carcass equations. This research indicates that real-time ultrasound measurements taken on live beef cattle can be used to effectively predict carcass composition.

## GENERAL INTRODUCTION

Due to the decline in market share over the past two decades, the beef industry has been challenged to shift from being a commodity-driven to a consumer-driven business. Providing consumers with the lean, palatable, wholesome product they desire has increased focus on the end product by all segments of the industry. Growth in alliance and specification programs, as well as carcass merit-based pricing systems are a testimony to these changes. These forms of value-based marketing have increased the emphasis placed on carcass traits by producers, as financial rewards are available for those providing a superior product.

Greater focus on the end product has stimulated demand for genetic evaluation of carcass traits. However, collection of progeny carcass data for use in expected progeny difference calculation by breed associations is time consuming, expensive, and requires extensive cooperation by various segments of the industry. In addition, the past inability to measure carcass traits on breeding animals has limited the amount of data available for these genetic evaluations. The use of real-time ultrasound has tremendous potential to alleviate these shortcomings. Scanning of yearling seedstock for carcass merit would reduce the dependency on progeny testing and shorten the time interval required for evaluation. Additionally, incorporation of ultrasound into structured sire evaluations would allow carcass merit to be evaluated at a proper endpoint and allow for maintenance of contemporary groups which are frequently disrupted by marketing procedures. However, these possibilities are contingent on the ability of real-time ultrasound to measure carcass traits in the live animal in a consistently accurate manner.

Another industry segment which can benefit from real-time ultrasound is the feedlot sector. Assessment of composition prior to slaughter would allow for marketing decisions to be made based on carcass specifications. Determination of fat cover and longissimus muscle area using ultrasound prior to slaughter would improve the end product and enable producers to be competitive in carcass merit-based pricing systems. In addition, evaluation of quality grade through real-time ultrasound prediction of intramuscular fat is now possible in both the live animal (Izquierdo, 1996) and carcass (Amin et al., 1995).

For true value-based marketing to become a reality, producers need to paid on the quantity and quality of the end product produced. Equations have been developed for predicting retail yield using postmortem carcass measurements (Murphy et al., 1960; Crouse and Dikeman, 1976; Miller et al., 1988), and are being applied to genetic evaluation programs. Likewise, prediction equations for determining the amount of saleable product based on live cattle measurements are needed. Carcass measures of fat cover and longissimus muscle area, which are included in carcass retail yield equations, can be measured on the live animal using ultrasound. Use of these measurements on the live animal to predict carcass retail product have shown promise (Herring et al., 1994b; Hamlin et al., 1995). Other carcass measurements that may explain a significant portion of the variation in retail yield, such as internal fat and sample cut composition (Hedrick, 1983; Shackelford et al., 1995), can not be readily determined on the live animal. Therefore, alternative live animal measurements that may be coupled with fat cover, longissimus muscle area, and weight to predict retail yield are needed. Two sites that have shown promise are rump fat (Wallace et al., 1977; Williams et al., 1997) and body wall thickness (Cross et al., 1973; Perkins et al., 1992c). Due to the expense of carcass fabrication and the relatively recent acceptance of ultrasound technology by the beef industry, few studies with large numbers of animals have been conducted to determine the efficacy of using real-time ultrasound and live animal measures to predict beef carcass composition. Development of equations that accurately predict carcass retail product with live animal measurements would add another level of capability to genetic evaluation programs.

Therefore, the objectives of this research project were: 1) determine the relationship between various real-time ultrasound measurements and carcass composition, 2) develop prediction equations for weight and percentage of beef carcass retail product using real-time ultrasound and live animal measurements, and 3) determine the accuracy of real-time ultrasound and live animal measurement-based equations for predicting beef carcass retail product.

## Dissertation organization

This dissertation is comprised of an abstract, a general introduction, an overall review of the literature, three individual papers, an appendix, and a general summary.

References are compiled for each paper. followed by the tables and figures. References cited in the general introduction. overall literature review. and appendix follow the general summary. Papers are written for submission to the Journal of Animal Science. and follow the Journal of Animal Science Style and Form (CBE Style Manual). The appendix contains additional results from this project not included in the three papers.

# LITERATURE REVIEW

## Predictors of Beef Carcass Retail Yield

*Fat thickness*

It is well documented that fat thickness is the single most important variable related to percentage retail yield in the beef carcass. Fat thickness over the ribeye at the 12th rib is the measurement most frequently used. Researchers who have identified fat thickness as the most important factor affecting cutability include Murphy et al. (1960). Brungardt and Bray (1963). Hedrick et al. (1965). Henderson et al. (1966). Epley et al. (1970), Crouse et al. (1975). Crouse and Dikeman (1976). Koch and Dikeman (1977) and Abraham et al. (1980). To account for any subcutaneous fat that may be removed during processing and natural variation in fat distribution across the entire carcass. adjustments to actual fat measurements may be necessary. Abraham et al. (1980) found correlations of -.79 and -.82 between cutability and actual fat thickness and adjusted fat thickness. respectively. Other researchers agree that adjustments are necessary (Crouse and Dikeman. 1976; Shackelford et al., 1995).

Among carcass traits. adjusted fat thickness is the most accurate predictor of percentage retail product yield. accounting for 67 to 70% of the variation (Powell and Huffman. 1968; Abraham et al.. 1980). Powell and Huffman (1968) showed that over 70% of the variation in carcass composition was accounted for by fat thickness. and found correlation coefficients of .89 with carcass fat and -.85 with carcass protein.

Parrett et al. (1985) reported correlations of -.43, .45, and -.65 between adjusted 12th rib fat thickness and percentage of carcass lean, fat, and boneless retail cuts. Similarly, Shackelford et al. (1995) reported correlations of -.76 and .80 between adjusted fat thickness and retail product yield or fat trim yield. These correlations were higher than those found for actual 12th rib fat thickness (r = -.73 and .77) in the same study. May et al. (1992b) reported simple correlations of -.69 and .84 between adjusted 12th rib fat thickness and boneless subprimal yield and percentage of trimmable fat, respectively.

In contrast, Reiling et al. (1992) found fat thickness to account for only 29% of the variation in yield of retail cuts. Abraham et al. (1980) reported fat thickness to have little effect on yield of boneless steak and roast meat in Charolais cattle with little fat cover.

Crouse and Dikeman (1976) reported fat thickness to be a valuable predictor of cutability both within and across breeds of sire, and the correlation between percentage of retail product and fat thickness was not affected by the additional variation associated with sire breeds. The high correlation between fat thickness and cutability percentage, and the consistency of this relationship across and within breed groups suggests that fat thickness would be a valuable predictor of cutability regardless of genetic origin (Crouse et al., 1975).

Measurement of fat thickness is more strongly related to percentage than weight of retail product. Williams et al. (1997) reported a correlation of .18 between adjusted carcass fat and kilograms of retail product. Other studies have reported higher correlations (Cole et al., 1962; Fitzhugh et al., 1965), due to an increase in fat thickness at heavier carcass weights. Epley et al. (1970) stated fat thickness was the least valuable predictor of total primal weight of retail cuts. However, fat thickness is highly related to the weight of trimmable fat in the beef carcass. Herring et al. (1994b) and Williams et al. (1997) found simple correlations of .51 to .64 between adjusted carcass fat thickness and total weight of trimmable fat. Several studies have found fat thickness to be a useful variable in predicting weight of retail product when combined with other traits (Cole et al., 1962; Fitzhugh et al., 1965; Herring, et al., 1994b; Williams et al., 1997).

Other subcutaneous as well as intermuscular fat measurements have been investigated at nearly every possible location on the carcass in attempts by scientists to find measurements most highly related to carcass composition. Wallace et al. (1977) found shoulder fat thickness to be the best variable for predicting percentage primal retail cuts and total retail yield ($R^2$ = .74 and .71, respectively), and even proposed this fat measurement could more accurately indicate yield in carcass grading programs than the conventional 12-13th rib fat measurement. Similarly, Kauffman et al. (1975) reported a strong correlation of -.77 between seam fat score and percentage of fat-free muscle. Although this measurement would be useful in explaining additional variation in cutability, its practical use in a commercial setting is questionable.

Cross et al. (1973) reported body wall thickness was significantly associated with percent fat trim, percent retail cuts, and weight of retail cuts (r = .69, -.61, and .41, respectively). Brungardt and Bray (1963) also reported a negative correlation between body wall thickness and percent retail cuts. Abraham et al. (1980) found body wall thickness measured 10.2 cm from the lateral end of the ribeye muscle to be a significant variable in models to predict percentage of boneless, closely trimmed retail cuts. However, the authors concluded that the body wall measurement did not sufficiently improve cutability equations when added to the four yield grade variables to warrant its inclusion.

In a comparison of three beef quantity prediction equations, Thackston et al. (1967) found fat thickness over the biceps femoris muscle to be negatively correlated with percent retail yield. Wallace et al. (1977) reported rump fat measured on the carcass to explain 37 to 40% of the variation in percentage of primal or total retail cuts. Although not as predictive as 12th rib fat, rump fat was useful when combined with carcass weight and percent kidney fat in models to predict retail yield or weight. Difficulties in obtaining measures of fat cover over the rump or round due to slaughter processing have resulted in limited data collection for this trait in the carcass.

Despite attempts of several researchers to identify alternative locations to quantify fat thickness, a single measure of fat cover opposite the longissimus dorsi muscle at the 12-13th rib continues to be the most efficient and accurate indicator of cutability in the beef carcass.

*Longissimus Muscle Area*

The cross-sectional area of the longissimus dorsi muscle at the 12-13th rib has long been the standard as an indicator of total carcass muscling. However, many researchers have found this measurement to have little predictive power for percentage retail product in the beef carcass (Hedrick et al., 1965; Birkett et al., 1965; Epley et al., 1970; Wallace et al., 1977), and its usefulness has been questioned (Wilson, 1992). Despite these findings, an assessment of total muscle in the carcass would be helpful in prediction equations. Therefore, longissimus muscle area continues to be used to evaluate the degree of muscling in the carcass, largely due to the simplicity with which this measurement may be taken.

Many studies have found longissimus muscle area to be significantly related to retail product weight or yield. Fitzhugh et al. (1965) reported correlations of .56 to .65 between longissimus muscle area and weight of boneless roast and steak meat. Cole et al. (1960) found a similar correlation of .59 between longissimus muscle area and carcass separable lean. Brackelsberg and Willham (1968) reported a correlation of .42 between longissimus muscle area and percent separable muscle. More recently, Shackelford et al. (1995) reported a correlation of .44 between longissimus muscle area and retail product yield across breed groups containing a large amount of variation in carcass measures and cutability. Similarly, Crouse et al. (1975) reported a correlation of .47 between longissimus muscle area and cutability across seven sire breeds, whereas Crouse and Dikeman (1976) found this correlation to be only .15 within breeds of sire.

The major cause of the positive association between longissimus muscle area and measures of weight of carcass lean is the positive correlation between longissimus muscle area and carcass weight (Cole et al., 1960; Cole et al., 1962; Fitzhugh et al., 1965; Epley et al., 1970). Cole et al. (1960) reported longissimus muscle area was associated with only five percent of the variation in separable lean when carcass weight was held constant, and found longissimus muscle area accounted for 27% of the variation in carcass weight. Fitzhugh et al. (1965) found correlations of .01 to .06 between the same variables at a constant carcass weight. Crouse et al. (1975) suggest that longissimus muscle area may be most useful in populations of cattle that are similar in weight.

Several researchers have noted that longissimus muscle area has the least predictive value for carcass cutability of the four yield grade factors (Brungardt and Bray, 1963; Epley et al., 1970; Crouse et al., 1975). Ramsey et al. (1962) stated that when ribeye area was omitted from yield grade calculations, the resulting grades were more highly related to separable lean than when ribeye area was included. Epley et al. (1970) found ribeye area alone to account for only 1% of the variation in percent primal retail cuts, and reported a decrease in $R^2$ of only .02 and an increase in the standard error of the estimate of only .07 for their prediction equation when ribeye area was excluded. Abraham et al. (1968) reported correlations of .18 and .24 between longissimus muscle area and weight and percentage of steak and roast meat, respectively, when carcass weight, fat thickness, and kidney and pelvic fat were held constant. The same study found longissimus muscle area to have a positive relationship with boneless cut weight and a negative relationship with cutability (r= .77 and -.18). Epley et al. (1970) agree that longissimus muscle area is more highly associated with weight than percentage of retail cuts. Hedrick et al. (1965) stated that fat thickness explained two to three times the variation in retail yield compared to longissimus muscle area.

However, ribeye area has been shown to contribute significantly to multiple regression equations for predicting cutability (Murphy et al., 1960; Brungardt and Bray, 1963; Abraham et al., 1968; Kauffman et al., 1975; Abraham et al., 1980; Parrett et al., 1985). Reiling et al. (1992) found longissimus muscle area to account for 26% of the variation in retail product percentage when used alone, and 46% when adjusted for sex differences. Williams et al. (1997) found carcass ribeye area to contribute significantly in prediction equations for both weight and percentage of retail cuts. In contrast, Herring et al. (1994b) reported that longissimus muscle area did not improve the precision of prediction models for either weight or percentage of retail cuts after carcass weight and fat thickness had been included in the prediction equations. Crouse et al. (1975) concluded that there is a strong relationship between breed groups for cutability and ribeye area, indicating that a measure of ribeye area may account for variation in cutability associated with breed groups. However, Cross et al. (1973) stated that regardless of genetic background, longissimus muscle area is the best measurement to include in prediction equations as an index of muscling in the carcass.

The relative importance of longissimus muscle area for predicting cutability within a group of carcasses may depend on the variability in fat thickness and retail yield compared to the variability in longissimus muscle area. Cross et al. (1973) indicated that longissimus muscle area may be more predictive in carcasses that have small variation in fat cover.

*Kidney, pelvic, and heart fat*

Studies have shown variable results regarding the usefulness of kidney, pelvic, and heart fat in predicting cutability. Kauffman et al. (1975) found percentage kidney, heart, and pelvic fat did not contribute sufficiently to warrant inclusion in prediction equations for percentage of fat-free muscle. Fitzhugh et al. (1968) also found kidney fat weight to not be related to the yield of roast and steak meat when combined with fat thickness and longissimus muscle area in a prediction equation. Reiling et al. (1992) showed percentage kidney, pelvic, and heart fat to explain only 3.3% of the variation in retail yield. Despite a moderate correlation of -.33 with retail product yield, Shackelford et al. (1995) found estimated kidney, pelvic, and heart fat percentage to only increase the $R^2$ of prediction equations by .02 when included with fat thickness, ribeye area, and carcass weight. In Simmental steers, Parrett et al. (1985), reported percentage kidney and pelvic fat to be significantly correlated with carcass chemical fat and lean but not boneless retail cut yield.

Others have found kidney, pelvic, and heart fat to be useful in prediction equations (Murphy et al., 1960; Brungardt and Bray, 1963; Abraham et al., 1968; Williams et al., 1997). Cross et al. (1973) reported that both weight and percentage of kidney and pelvic fat to be associated with percentages of fat trim, bone, and retail cuts. Studies have shown percentages of kidney, pelvic, and heart fat to be second in importance only to fat thickness over the ribeye in predicting cutability (Abraham et al., 1980). Epley et al. (1970) found percentage of kidney, pelvic, and heart fat to explain the most variation in retail cut yield when the effects of a single yield grade variable were evaluated while holding the other three constant. Alone, kidney pelvic, and heart fat has been shown to account for 33-34% of the variation in retail cut yield, and has been the first variable to enter prediction models using stepwise regression (Herring et al., 1994b). Although lower in its predictive value that fat thickness, percentage of kidney, pelvic, and heart fat has been shown to be useful both across and within breed groups (Crouse et al., 1975; Crouse and Dikeman, 1976). Abraham et al. (1980) attributed kidney, pelvic, and heart fat's usefulness in prediction equations to its strong correlation with percentage of seam fat ($r = .59$).

Kauffman et al. (1975) suggested elimination of the kidney and pelvic fat variable from USDA standards due to its subjectivity, and associated lack of precision and repeatability along with allowing for greater processing efficiency. Work by Crouse and Dikeman (1976) showed variation in actual kidney and pelvic fat was more highly associated with variation in retail product yield than estimated kidney and pelvic fat (r = -.42 and -.39). Crouse et al. (1986) reported an average effect of two percentage points in cutability for carcasses with and without kidney and pelvic fat, and the correlation between cutability calculated with and without kidney and pelvic fat was high (r = .98). However, Abraham et al. (1980) found cutability of kidney, pelvic, and heart fat-in carcasses could be estimated better than the cutability of carcasses with the kidney, pelvic, and heart fat removed.

*Carcass weight*

The usefulness of carcass weight in a prediction equation depends upon the purpose of the equation. Several studies have shown carcass weight to be the best predictor of weight of separable lean or total product (Cole et al., 1962; Fitzhugh et al., 1965, Abraham et al., 1968; Epley et al., 1970). Birkett et al. (1965) found a simple correlation of .97 between carcass weight and weight of closely trimmed cuts. Epley et al. (1970) reported carcass weight to account for 85% of the variation in weight of retail cuts, indicating carcass weight was the single best predictor of weight of retail cuts. Others concur (Herring et al., 1994b; Williams et al., 1997).

Early studies consisting of primarily British-breed cattle reported negative correlations between carcass weight and percentage of separable lean (Cole et al., 1962; Birkett et al., 1965; Fitzhugh et al., 1965; Epley et al., 1970; Abraham et al., 1980). In a study using 288 steer carcasses from 11 sire breeds, Apple et al. (1991) reported moderately low but significant negative correlations between hot carcass weight and percentage of total retail product (r = -.30 and -.28), at .76 and 0 cm of fat trim, respectively. Others found carcass weight to be a poor indicator of the percentage of edible muscle or boneless steak and roast meat (Brungardt and Bray, 1963; Abraham et al., 1968). Reiling et al. (1992) reported hot carcass weight to account for less than 1% of the variation in retail yield across sexes.

Crouse and Dikeman (1976) observed a correlation of -.18 between carcass weight and percentage of retail product on an overall breed group basis; however, on a within breed group basis this correlation increased to -.46. Similarly, Crouse et al. (1975) found correlations of -.07 and -.42 across and within sire breeds, and found minimal improvement in $R^2$ value for prediction models including hot carcass weight. Kauffman et al. (1975) questioned the negative impact of carcass weight in USDA yield grading standards and stated that heavier carcasses may originate from larger, later maturing, leaner cattle. These results indicate that across breeds the usefulness of carcass weight as a predictor of cutability may be influenced by differences in physiological growth patterns, as heavier carcasses may actually have higher cutabilities. However, within a breed type, carcass weight is negatively related to cutability as heavier carcasses tend to have more fat cover.

*Marbling*

Subjective marbling scores serve as the foundation for beef carcass quality grades and have received attention by some researchers as an indicator of carcass cutability. Wallace et al. (1977) found marbling score to explain 56 and 59% of the variation in percentage of primal and total retail yield, respectively, in Hereford and Angus steers. Crouse and Dikeman (1976) reported correlations between marbling score and percentage retail product of -.38 within breeds and -.48 across breed groups. Kauffman et al. (1975) reported marbling score to be superior to both kidney, pelvic and heart fat and hot carcass weight in accounting for variation in percent fat-free muscle. When used in combination with another variable (fat thickness, ribeye area, seam fat score), marbling score increased the $R^2$ values of prediction equations .04 to .33 and the authors suggested marbling may have a dual role as a measure of quality and quantity in the beef carcass (Kauffman et al., 1975). Parrett et al. (1985) also found marbling was an important factor for predicting percentage of boneless retail cuts in Simmental steers, and Abraham et al. (1980) found marbling had the same effect on $R^2$ value as using kidney, pelvic, and heart fat for predicting carcass yield. Marbling score has a positive relationship with seam fat and total fat in a carcass or wholesale cut (Johnson et al., 1989; Jones et al., 1990), which may make it useful as an additional parameter in explaining variation in cutability.

*Sample Cuts*

Many researchers have demonstrated that the composition of a particular wholesale or sample cut may be highly associated with whole carcass composition. Since the wholesale round represents a large portion of the total carcass muscle, it has been the most frequently evaluated. Cole et al. (1960) reported separable lean of round accounted for 90% of the variation in total carcass separable lean. For each 1 unit increase in separable round lean, these researchers found a corresponding increase of 2.94 units in separable lean in the whole carcass. Brungardt and Bray (1963) found percent trimmed round to have the largest simple correlation coefficient of any single measurement with retail yield (r = .83). Percent trimmed round accounted for 69% of the variation in retail yield and 56% of the variation in predicted percentage of carcass muscle. Reiling et al. (1992) found inclusion of percentage of trimmed round with the four factors in the USDA retail yield equation to improve the $R^2$ from .48 to .67. Alone, percentage of trimmed round accounted for 57% of the variation in retail yield in this study, whereas Brackelsberg and Willham (1968) reported only 30%. Other studies confirm that percent boneless round is highly correlated (r = .71 to .83) with percent retail yield or percent separable muscle (Henderson et al., 1965; Crouse and Dikeman, 1975; Rouse et al., 1988). Similarly, weight of the trimmed round is highly related to total weight of retail product (Tuma et al., 1967; Brackelsberg et al., 1968).

In contrast, Cross et al. (1973) stated that the use of either trimmed or untrimmed round weight in cutability determination was not sufficiently more accurate than longissimus muscle area in measuring the contribution of muscling to cutability. They found trimmed round weight to have a correlation of .94 with weight of retail cuts, but only a correlation of .03 with percent retail cuts. Longissimus muscle area had correlations of .77 and .30 with the same carcass cut-out endpoints.

Other sample and primal cuts have also been evaluated as to their predictive power. Hankins and Howe (1946) found the muscle, fat, and bone of the 9-10-11th rib section were highly associated with the corresponding components of the entire carcass, and developed prediction equations which have been widely used to estimate carcass composition. Chemical composition of the 9-10-11 rib section has been shown to be useful in predicting retail product yield (Crouse and Dikeman, 1976; Miller et al., 1988). Shackelford et al. (1995) reported wholesale rib dissection traits to be the best single predictors of carcass retail yield as well as fat and bone yield. This study found the wholesale rib variables to be better predictors than 9-10-11 rib variables because the wholesale rib represented a larger proportion of the entire carcass. Parrett et al. (1985) investigated the relationship between the percentage fat and lean in various wholesale cuts and whole-carcass percentage fat and lean, and found the wholesale chuck had the highest correlation with carcass fat and lean components.

In general, composition of a particular wholesale cut is an accurate indicator of whole-carcass composition. However, due to the time, labor, and expense of collecting partial cut-out, the use of this data and resulting prediction equations has been limited to scientific studies and not been applied to the industry.

*Linear Measurements*

Various linear measurements have been used in an attempt to quantify differences in retail product weight and yield in beef carcasses. Linear measurements of beef carcasses are more highly related to weight than to percentage of carcass components due to their relationship with carcass weight (Abraham et al., 1968; Hedrick, 1983). Indeed, Cross et al. (1973) reported correlations of .72 and -.26 between carcass length and retail cut weight and percentage, respectively. The same study found width of round was more highly associated with weight of boneless retail cuts (r = .73) than was length of the round (r = .30). Brungardt and Bray (1963) and Abraham et al. (1968) reported width of the round was more highly related to retail yield than was length of the round. In contrast, Birkett et al. (1965) and Cole et al. (1960) reported round length to be more highly correlated with carcass separable lean than round width.

Carcass length, hindquarter length, round length, chuck thickness, round thickness, and depth of chuck are better predictors of cutability within a sire breed group than across breeds of sire. Crouse and Dikeman (1976) stated that within a sire breed, shorter, thicker carcasses yielded higher percentages of retail product. However, across breeds of sire, longer carcasses with thicker rounds had higher percentages of retail product.

*Subjective Measures*

Live animal evaluation of weight, muscle, and fat cover have been used in the beef cattle industry for many years to establish grade and price. The value of conformation as a predictor of carcass composition has been the subject of much debate for decades. Because fatter cattle and carcasses tend to be given higher conformation scores, the degree to which variation in fatness is accounted for will determine the effectiveness of conformation scores to explain differences in actual composition (Hedrick, 1983). Cross et al. (1973) found carcass conformation scores were correlated to percent fat trim (r = .42), weight of retail cuts (r = .59), and percent retail cuts (r = -.25), indicating higher conformation scores related to increases in percent fat and decreases in percentage of retail cuts. Kauffman et al. (1975) reported carcass round muscle scores were not related to percentage of fat-free muscle, but were positively correlated with muscle to bone ratio (r = .78). Others agree that subjective measurements of carcass muscling have little value in estimating cutability (Butler, 1957; Abraham et al., 1968), especially when combined with objective carcass traits (Crouse and Dikeman, 1976; Abraham et al., 1980).

In live cattle, Brackelsberg and Willham (1968) found live muscle or conformation score to be unrelated to percentage of muscle or fat trim in the carcass. In contrast, live condition score was moderately correlated with percentage of fat trim in the carcass (r = .29 to .44). Herring et al. (1994b) reported similar results in a more recent study with Hereford crossbred steers. Gregory et al. (1962) stated that purchase of cattle using carcass measures would be more equitable because subjective live scores and estimates accounted for only 20 to 25% of the variation in carcass traits that affect value. However, studies conducted by May et al. (1992a, 1992b) outline the live and carcass value advantage of thick-muscled cattle (based on USDA standards for grades of feeder cattle) as retail cut fat trim level decreases.

Although conformation measured subjectively is not a significant factor in predicting cutability of beef carcasses, conformation is important in current production and marketing systems and contributes to aesthetic value of live animals and carcasses.

## The Relationship Between Real-time Ultrasound and Carcass Measurements in Beef Cattle

The use of ultrasound for fat and muscle prediction is not a new technology, and has been used for over 35 years to determine body composition in live animals (Stouffer et al., 1959). Over time, technological advancements have improved ultrasound equipment and currently real-time ultrasound machines are most commonly accepted for use in beef cattle. Prior to 1991, the Technicare 210 DX and G.E. Datason machines were most frequently used (Houghton and Turlington, 1992). Since that time, the Aloka 500V, which allows for the entire longissimus muscle to be imaged with a long transducer, has been the instrument of choice (Duello, 1993; Herring et al., 1994a).

The accuracy of ultrasound measurements of carcass traits has been investigated for many years. The results indicate a great deal of variability that may be attributed to several sources including type of machine and expertise of the technician. Additionally, several statistics have been used to describe the accuracy of ultrasound in measuring carcass traits.

The most commonly used statistic in the literature to describe accuracy data is the correlation coefficient. Duello (1993) summarized correlations between ultrasound and carcass measures of fat thickness and longissimus muscle area across studies using various machines. Correlations between ultrasonic and carcass measurements of fat thickness ranged from .75 to .96, and from .20 to .90 for longissimus muscle area. The average correlations were .86 and .73 for fat thickness and longissimus muscle area, respectively. However, it should be noted that the majority of these studies were conducted prior to the use of the Aloka 500V machine. Although correlations are useful in describing the relationship between ultrasound and carcass measures, they also have their limitations including: 1) population variation influences correlation coefficients (a larger than normal variation will produce high correlations, whereas a uniform population will result in lower correlations); 2) correlation coefficients do not reflect bias (consistent over or under-estimation of carcass measurement using ultrasound); and 3) correlation coefficients are not easily understood by producer groups (Houghton and Turlington, 1992).

Due to these limitations, alternative methods of describing accuracy have been used. One method is to report the data in the form a frequency distribution (proportion of ultrasound measurements within a specific range of the carcass measurement) (Houghton and Turlington, 1992). Mean difference (bias), absolute mean difference, and mean difference between ultrasound and carcass measures expressed as a percentage of the carcass measure have also been used (Perkins et al., 1992a; Perkins et al., 1992b; Duello, 1993). Another method of assessing accuracy in the standard error of prediction, which is thought to be the primary measure of the ability to correctly rank or predict differences between animals (Robinson et al., 1992). Robinson et al. (1992) reports that this statistic has an advantage over the mean absolute difference because by squaring differences, a few large errors are considered more serious than a greater number of small errors. Currently, the standard error of prediction, along with the standard error of repeatability and bias are the statistics used by the Beef Improvement Federation to certify technicians for proficiency in the use of ultrasound. Regardless of how accuracy is described, there is considerable variation between operators and machines in the ability of ultrasound to predict carcass traits.

Several factors have been investigated as potential causes of differences between ultrasound and carcass measures. Turlington (1990) reported that carcass position during chilling influences carcass measurements, and therefore influences the perceived accuracy of ultrasound. In this study, pigs were scanned prior to slaughter and one half of each carcass was hung on the rail in the traditional manner while the other half was chilled in a standing position. Results indicated no significant differences for fat measurements taken on the live animal and standing carcass. However, fat measurements taken on the hanging carcass exceeded those for the live animal and standing carcass. Ultrasonic measurements of longissimus muscle area were intermediate to the hanging (largest measurement) and standing (smallest measurement) carcass.

Additionally, carcass measurements are not taken without error. Robinson et al. (1992) reported an difference of 1.3 $cm^2$ between carcass longissimus muscle area tracers, and attributed this difference to the tendency of tracers to deviate either to the inside or outside of the muscle boundary. The same study found average correlations were highest between scan data and the mean of the left and right sides of the carcass, rather than the particular side scanned; suggesting that much of the variation between sides of the carcass is due to handling and dressing procedures rather than biological differences. Similarly, Smith et al. (1992) compared measuring carcass longissimus muscle area with a dot grid versus an acetate tracing analyzed on an electronic digitizing board and found the two measurement procedures to have a correlation of .89.

Robinson et al. (1992) evaluated accuracy of ultrasound measures from three accreditation clinics. The average correlation between ultrasound and carcass measurements for rump fat, rib fat, and longissimus muscle area were .92, .90, and .87, respectively, while standard errors of prediction between live and carcass measurements were 1 mm for fat depths and 5 $cm^2$ for longissimus muscle area. Results also indicated a high degree of repeatability as the standard errors between repeated measures by the same technician were .77 mm, .62 mm, and 3.94 $cm^2$ for rump fat, rib fat, and longissimus muscle area, respectively. The authors concluded that experienced, well trained technicians can measure fat depths nearly as accurately as on the carcass, and a very experienced sonographer can measure longissimus muscle area only marginally less accurately than it can be measured on the carcass.

In a study using 546 steers and heifers scanned by two technicians. Perkins et al. (1992a) reported simple correlation coefficients between ultrasonic and carcass measures of .75 for 12-13th rib fat thickness and .60 for longissimus muscle area. Correlations were similar for the two technicians. When expressed as percentages of carcass measurements, the average absolute differences indicated error rates of 20.6% for fat thickness and 9.4% for longissimus muscle area. In this regard, the general conclusion of many studies that ultrasound is more accurate at measuring fat cover versus muscle area is incorrect. Frequency distributions were also reported, with ultrasound fat thickness within 2.5 mm of the carcass measure 70% of the time, and ultrasound longissimus muscle area within 6.5 $cm^2$ of the carcass measurement 53% of the time.

Waldner et al. (1992) ultrasounded Brangus bulls from 4 to 24 months of age, and slaughtered 10 bulls every four months to determine carcass composition. Scanned mean fat thickness was most accurate at 16 months, and was not different from the carcass mean fat thickness (95% of the time the error in estimation was < 3.3 mm). Scanned mean longissimus muscle area was most accurate at 12 months of age (95% of the time the error in estimation was < 20.0 $cm^2$). The authors concluded that scanning of longissimus muscle area at 12 months and fat thickness at 12 or 16 months was sufficiently accurate to characterize groups of bulls, however, measurements at other months should not be considered accurate for either individuals or groups of bulls.

Smith et al. (1992) conducted two studies to evaluate accuracy of ultrasound. In the first experiment, 315 yearling steers of various breed type were used, whereas 137 steers were evaluated in the second. Results indicated 74% of the ultrasonic estimates of fat thickness were within 2.54 mm of carcass values ($r = .81$) and longissimus muscle area was predicted within 6.54 cm$^2$ of the carcass measure 47% of the time ($r = .43$). Similar correlations between ultrasonic and carcass fat thickness were reported for the second experiment ($r = .82$), but only 62% of the ultrasound measurements were within 2.54 mm of carcass fat thickness indicating the estimates were more biased. However, ultrasound longissimus muscle area improved to having 53% within 6.54 cm$^2$ of the carcass measure ($r = .63$). Conclusions drawn by the authors stated ultrasound measurements of fat thickness are precise and accurate, but muscle area estimates are inconsistent.

In an extensive three year study using 497 steers and 247 bulls, Duello (1993) reported ultrasound to slightly underestimate fat thickness (.32 mm) and overestimate longissimus muscle area (1.47 cm$^2$) compared to carcass measurements. Mean absolute values of the differences between ultrasound and carcass measurements, which are an indication of the average error, were 2.3 mm for fat thickness and 5.09 cm$^2$ for longissimus muscle area. Standard errors of prediction corrected for bias were 2.9 mm and 6.45 cm$^2$, respectively, for the same traits. These results support the notion that ultrasound may predict carcass fat thickness with a high degree of accuracy. Although results are in general more variable, longissimus muscle area may also be estimated accurately by a proficient technician.

The magnitude and direction of the difference between ultrasound and carcass measures (bias) may be affected by the level of fat thickness or size of the longissimus muscle. Herring et al. (1994a) reported ultrasound overestimates fat thickness and longissimus muscle area in leaner and lighter-muscled steers and underestimates these traits in fatter and heavier-muscled steers. Smith et al. (1992) reported that longissimus muscle area is overestimated in steers when carcass longissimus muscle area is < 71 $cm^2$ and underestimated if carcass longissimus muscle area is > 84 $cm^2$. Duello (1993) also found leaner cattle (< 7.6 mm) are overestimated and fatter cattle (> 12.7 mm) are underestimated relative to the carcass measure with ultrasound. Other researchers concur with these trends (Brethour, 1992; Perkins et al., 1992a; Robinson et al., 1992; Duello, 1993; Herring et al., 1994a), although the carcass measure at which biases increase in magnitude is variable from study to study. Perkins et al. (1992a) notes underestimation occurs more frequently than overestimation for both traits. In contrast, Waldner et al. (1992) found bulls with smaller (< 70 $cm^2$) longissimus muscle areas were underestimated and those with larger (> 85 $cm^2$) were overestimated. Fat thickness and longissimus muscle area do not appear to affect repeatability of measures taken on the same animal by the same technician (Herring et al., 1994a).

Duello (1993) reported standard errors of prediction gradually increased from 1.6 mm in cattle with carcass fat thickness of < 5.1 mm to 3.3 mm for cattle with > 12.7

mm carcass fat. However, standard errors of prediction for longissimus muscle area were similar (5.63 to 6.16 $cm^2$) in cattle with < 90.3 $cm^2$ carcass longissimus muscle area and then decreased slightly (5.03 $cm^2$) for those > 90.3 $cm^2$; suggesting that magnitude of longissimus muscle area may not influence the ability of ultrasound to predict carcass measurements.

Stouffer (1988) attributed inaccuracies in measuring ribeye area to: 1) dirt, hide thickness, and hair; 2) degree of fat thickness; 3) ability to match halves of the longissimus muscle using the split-screen technique; and 4) parallel interfaces to the ultrasound sound waves. The perception that increased fat cover results in poorer image quality, and therefore causes less accurate estimation of longissimus muscle area in fatter cattle was also investigated by Duello (1993). Results indicated that bias increased as carcass fat thickness increased, with fatter animals increasingly overestimated for longissimus muscle area with ultrasound. However, standard errors of prediction for longissimus muscle area did not consistently increase as fat thickness increased.

Herring et al. (1994a) evaluated the effects of machine, technician, and interpreter on ultrasound measures of fat thickness and longissimus muscle area. Images were taken on two consecutive days by three technicians who varied in experience. Repeatabilities ranged from .69 to .90 for fat thickness, and from .36 to .90 for longissimus muscle area. Absolute mean differences between ultrasound and carcass measures of longissimus muscle area varied 4.79 $cm^2$ between technicians. All technicians were found to be similarly accurate for fat thickness. However, large differences existed between the three technicians to accurately predict longissimus muscle area. These differences were attributed to both the imaging and interpretation processes, and it was concluded by Herring et al. (1994a) that not all technicians are qualified to accurately predict carcass traits with ultrasound.

In contrast, Perkins et al. (1992b) reported repeatability correlations for longissimus muscle area of .83 and .84 for two different technicians, and .90 and .97 for fat thickness. Ultrasound measures for these traits were not found to be different between experienced technicians. Waldner et al. (1992) found increased level of operator skill (four technicians were used) did not improve the accuracy of fat thickness or longissimus muscle area measurements, whereas increased level of skill of the interpreter of scans did improve the accuracy of longissimus muscle area estimations. McLaren et al. (1991) agree that image interpretation may be a larger source of variation than image collection. Collectively, results of these studies may suggest that people with limited experience may be trained to collect images equal to those of experienced operators. However, image interpretation requires a great deal of experience and skill to achieve high accuracy levels.

Herring et al. (1994a) also evaluated the effect of machine on accuracy. Two machines were used, an Aloka 210DX (10.7 cm transducer) and an Aloka 500V (17.2 cm transducer). Measurements using the Aloka 500V were more repeatable and had smaller absolute differences for longissimus muscle area than the Aloka 210DX for all technicians. Differences in accuracy measures between the two machines were most evident for the technician with the least experience. These advantages were attributed to transducer size, and it was indicated accurate longissimus muscle area determination with ultrasound is more difficult with machines requiring split-screen imaging than with machines that allow complete imaging of the entire muscle boundary in a single scan. For measurement of fat thickness, the two machines were similar in accuracy. In contrast, Anderson et al. (1983) found no differences between various real-time machines for predicting carcass composition.

It is evident that accurate prediction of carcass traits in live beef cattle is attainable through the use of real-time ultrasound. In general, measurements of fat thickness are more closely associated with the carcass measures than are estimates of muscle area. However, with experienced, well-trained technicians ultrasound is an accurate predictor of carcass longissimus muscle area (Robinson et al., 1992; Duello, 1993; Herring et al., 1994a). It is likely that further improvements in accuracy may be obtained as the technology improves and systems for image interpretation advance.

## The Use of Ultrasound Measurements to Predict Beef Carcass Retail Yield

Although several equations have been developed for predicting retail yield and composition using postmortem carcass measurements, to date, most studies involving ultrasound technology have investigated the relationship and accuracy of ultrasound measured traits relative to the corresponding measurement in the carcass. Few studies have focused on ultrasound measured traits as a means to predict beef carcass retail yield.

Wallace et al. (1977) ultrasonically evaluated subcutaneous fat thickness over the shoulder, rib, lumbar, and rump and longissimus muscle area and compared prediction equations using ultrasound and carcass measures for estimating weight and percentage retail yield. They found that ultrasound could accurately measure fat at the various locations, and reported rib and lumbar fat thickness to be most highly correlated with percentage of primal or total retail yield ($R^2$ = .47 to .60). Rib fat, in combination with live weight, accounted for the most variation in weight of total product. Prediction models developed from carcass measurements accounted for more of the variation in retail yield than ultrasound measurements. However, neither carcass nor ultrasound-measured ribeye area improved prediction models for percentage or weight of retail product although carcass and ultrasound longissimus muscle area were highly correlated (r = .58 to .77).

Miller et al. (1988) reported 12th rib, shoulder, and rump fat thickness measured with ultrasound to account for a large portion of the variation in percentage carcass fat ($R^2$ = .72, .69, and .72, respectively). In agreement with Wallace et al. (1977), the authors reported little improvement in prediction equations when ultrasound longissimus muscle area was incorporated. In a subset of fed steers, prediction equations using ultrasound traits accounted for 71% of the variation in percentage carcass fat and yield grade parameters accounted for 77% of the variation.

Faulkner et al. (1990) developed prediction models for carcass chemical composition in cows using live and carcass measures. Equations using live measures of 12th rib ultrasound fat thickness, live weight, and hip height were similar in their accuracy ($R^2$ = .42 to .90) for predicting carcass composition to those developed from carcass measures ($R^2$ = .43 to .92). Bullock et al. (1991) also found ultrasound and other objective live measures to be as accurate in predicting cow composition as carcass measures.

Hamlin et al. (1995) ultrasonically measured feedlot steers representing 11 sire breed groups for fat thickness and longissimus muscle area to predict carcass retail yield parameters. Equations using ultrasound fat thickness alone explained 58 to 64% of the variation in percentage of trimmable fat or retail product at two fat trim levels. Ultrasound longissimus muscle area was not an important predictor of retail product percentage ($R^2 < .15$), but was correlated with total weight of retail product (r = .46 to .48). When ultrasound fat thickness and longissimus muscle area were combined with live weight in equations to predict percentage of retail product, $R^2$ values ranged from .61 to .65 compared to .75 to .76 for carcass yield grade parameters. The authors concluded that ultrasonic predictors explained about 10% less variation in retail product percentage than did carcass measures. Recio et al. (1986) agreed that live animal ultrasonic prediction of retail yield is slightly less predictive than using carcass measurements.

In an effort to predict retail yield with accuracy and precision similar to that of carcass measures, researchers have investigated other measurement sites that are easily obtainable on the live animal other than traditional 12-13th rib fat thickness and longissimus muscle area. Johns et al. (1993) studied alternative fat thickness and muscle thickness measurements using ultrasound and their relationship to lean and fat composition in beef steers. Fat measures taken at the 12-13th rib, 15 to 20 cm lateral to the spinal column and hip bone, 15 to 20 cm posterior to the rump lateral region, and a point one-half the distance between the hip and pin bone were correlated -.50, -.58, -.43, and -.48, respectively with carcass lean percentage and .83, .42, .63, and .42, respectively, with percentage of carcass fat. The same study reported correlations of .59 and .42 between ultrasound measures of the biceps femoris muscle depth and gluteus medius muscle depth, respectively, with percentage of carcass lean. Similarly, Perkins et al. (1992c) found ultrasound measured body wall thickness and rib interface intermuscular fatness were significantly correlated to various carcass dissection parameters. However, these measures added little predictive power for retail yield beyond ultrasonic 12th rib fat thickness and longissimus muscle area.

Williams et al. (1997) conducted a study using 198 Angus and Hereford steers in which live-animal ultrasound measurements of rump fat thickness and biceps femoris muscle depth were used along with 12-13th rib fat thickness and ribeye area to predict retail yield and trimmable fat in beef carcasses. It was found that ultrasound rump fat and 12-13th rib fat were the best single predictors of percentage retail product and trimmable fat, accounting for 24 and 22% of the variation, respectively. The addition of the rump fat measurement to models including live weight, ultrasound fat thickness, and ultrasound ribeye increased the $R^2$ from .18 to .32 for prediction of retail product percentage, and from .85 to .87 for weight of retail product. The inclusion of ultrasound biceps femoris muscle depth did not increase the magnitude of the $R^2$ for the same equations. Adding ultrasound measures of rump fat and biceps femoris muscle depth to the model using final weight, ultrasound fat thickness, and ultrasound ribeye area to predict weight and percentage of trimmable fat increased coefficients of determination from .53 to .61 and from .25 to .36, respectively. Ultrasound rump fat thickness was consistently a significant variable in stepwise regression equations to predict either retail product weight or percentage, and explained an additional 14% of the variation for percentage of retail product when included in models with other live animal measurements. The authors concluded that ultrasound rump fat thickness was the variable that increased the $R^2$ value for retail product percentage using live animal measures above those found for carcass measurements.

In addition to alternative measurement sites for fat thickness and muscle, subjective scores for overall fatness/trimness, muscle, and frame of the live animal have been investigated for use along with ultrasonically measured traits to predict carcass composition. Herring et al. (1994b) investigated these visual scores and traditional ultrasound measurements relative to their ability to predict retail product expressed as a percentage or weight defined three ways: including only retail cuts from round, loin, rib, and chuck; retail cuts from the round, loin, rib, and chuck along with lean trim; and total retail product from the entire carcass. Visual trimness score accounted for the most variation in percentage retail cuts from the round, loin, rib, and chuck ($R^2$ = .29 to .32), whereas ultrasound 12-13th rib fat thickness explained the most variation in percentage of retail product when lean trim was included ($R^2$ = .24 to .27), or for the entire carcass ($R^2$ = .24 to .27). Interestingly, ultrasound 12-13th rib fat thickness was not a significant variable included in models for predicting percent retail cuts from the round, loin, rib, and chuck. Ultrasound longissimus muscle area accounted for 5 to 10% additional variation when added to equations utilizing fat measurement for predicting percentage of retail product. When yields were expressed on a weight basis, live animal weight accounted for 65 to 77% of the variation. However, ultrasound longissimus muscle area and visual trimness score were also used in the final prediction model for each weight yield (final $R^2$ ranging from .78 to .84). Rank correlations between actual and predicted retail yields (percentage or weight) using live animal and carcass equations were not different from each other, suggesting that live equations ranked the animals equally as well as carcass equations.

Collectively, the literature would indicate that equations derived from ultrasound and live animal measures are useful in predicting beef cattle carcass composition. The ability of ultrasound-derived models to equal those developed from carcass measures will likely depend on the accuracy of the ultrasound measure. It is also important to note that individual carcass traits are only indicators of total carcass composition, and thus ultrasound serves to predict these predictors. As previously reviewed. ultrasound also offers opportunity to measure traits not easily quantified on the carcass (i.e.. rump fat). which may enhance the predictive power of this technology.

# THE RELATIONSHIP BETWEEN REAL-TIME ULTRASOUND MEASUREMENTS AND CARCASS FAT THICKNESS AND LONGISSIMUS MUSCLE AREA IN BEEF CATTLE

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S. P. Greiner[1], G. H. Rouse[1], D. E. Wilson[1], L. V. Cundiff[2], and T. L. Wheeler[2]

## Abstract

Five hundred thirty-four steers were evaluated in 1994 (n = 282) and 1995 (n = 252) to determine the accuracy of ultrasonic estimates of carcass 12-13th rib fat thickness (CFAT) and longissimus muscle area (CREA). Within 5 d prior to slaughter, steers were ultrasonically measured for 12-13th rib fat (UFAT) and longissimus muscle area (UREA) using an Aloka 500V real-time ultrasound machine equipped with a 17.2 cm, 3.5 MHz linear transducer. Overall, correlation coefficients between UFAT and UREA with CFAT and CREA were .89 and .86, respectively. Correlations for UFAT with CFAT were similar between years (.86 and .90), while the relationship between UREA and CREA was stronger in 1994 (r = .91) than in 1995 (r = .79). Differences between ultrasonic and carcass measurements were expressed on both an actual (FDIFF and RDIFF) and absolute (FDEV and RDEV) basis. Mean FDIFF and RDIFF indicated

[1]Department of Animal Science, Iowa State University, Ames, IA 50011.
[2]Roman L. Hruska U.S. Meat Animal Research Center, ARS, USDA, Clay Center, NE 68933.

that ultrasound underestimated CFAT .06 cm and overestimated CREA .71 $cm^2$ across both years. Overall mean FDEV and RDEV, which are an indication of the average error rate, were .16 cm and 3.39 $cm^2$, respectively. Analysis of year effects revealed FDIFF, FDEV, and RDEV were larger ($P < .01$) in magnitude in 1995 than 1994. Further analysis of FDEV indicated that leaner (CFAT < .51 cm) cattle were overestimated and fatter (CFAT > 1.02 cm) cattle were underestimated with ultrasound. Similarly, steers with small CREA (< 71.0 $cm^2$) were overestimateed and steers with large CREA (> 90.3 $cm^2$) were underestimateed. The thickness of CFAT had a significant ($P < .05$) effect on the error of UFAT and UREA measurements with leaner animals being more accurately evaluated for both traits. Standard errors of prediction (SEP) adjusted for bias of ultrasound measurements were .20 cm and 4.49 $cm^2$ for UFAT and UREA, respectively. Differences in SEP were observed for UREA but not UFAT by year. These results indicate that ultrasound can be an accurate estimator of carcass traits in live cattle when measurements are taken by an experienced, well trained technician. Although significant ($P < .01$) differences were noted for accuracy variables between years, these differences were small in magnitude.

## Introduction

The use of ultrasound technology to predict carcass traits in live cattle is not a new concept, as ultrasound has been used for over 35 years to determine body composition in live animals (Stouffer et al., 1959). Generally, most researchers have found ultrasound to estimate carcass fat with an acceptable degree of accuracy (Wallace et al., 1977; Brethour et al., 1992). Results for longissimus muscle area have been less conclusive (Smith et al., 1992; Waldner et al., 1992). Development of a longer ultrasound transducer, designed specifically for cattle use, which allows for imaging of the entire longissimus muscle area has resulted in improved accuracy of this trait (Herring et al., 1994).

Most studies have focused on the effects of animal, technician, and machine on ultrasound accuracy (McLaren et al., 1991; Perkins et al., 1992a; Herring et al., 1994). However, variation in ultrasound accuracy by the same technician scanning similar populations of cattle over time has not been investigated. Large differences in the accuracy of ultrasound in successive years has implications if producers are to make genetic progress by using this technology on breeding animals. Therefore, the objective of this study was to determine the relationship between ultrasound and carcass measures of 12-13th rib fat and longissimus muscle area in a large population of genetically diverse cattle. Additionally, the effect of year on ultrasound accuracy when measurements were taken by an experienced, well trained technician was evaluated.

## Materials and Methods

This study was conducted in cooperation with the Roman L. Hruska U.S. Meat Animal Research Center (**MARC**), Clay Center, NE. Five hundred thirty-four calf-fed steers from the 1993 (n = 282) and 1994 (n = 252) calf crops of Cycle V of the Germ Plasm Evaluation program were used. Cycle V $F_1$ calves were produced by mating Hereford, Angus, and MARC III (1/4 Red Poll, 1/4 Hereford, 1/4 Pinzgauer, 1/4 Angus) dams to Hereford, Angus, Tuli, Boran, Belgian Blue, and Brahman bulls.

Steers were fed a corn-corn silage diet from weaning to slaughter. The growing diet contained 2.7 Mcal ME/kg DM and 12.9% CP and the finishing diet fed from approximately 320 kg to slaughter contained 3.04 Mcal ME/kg DM and 10.9% CP. Beginning in mid-May, representative samples of steers (balanced across breed groups) were slaughtered serially in slaughter groups spaced approximately 21 d apart. Data used in this study includes all 4 slaughter groups in 1994 and the final 3 slaughter groups in 1995. Steers were slaughtered at a commercial packing facility. Following a 24 h chill, carcasses were evaluated for USDA yield and quality grade factors (USDA, 1989) by MARC personnel. Fat thickness used to assess ultrasound accuracy was an unadjusted measurement taken 3/4 the length ventrally over the longissimus dorsi muscle (**CFAT**). Longissimus muscle areas (**CREA**) were traced on acetate paper and measured later with a planimeter.

Within 5 d prior to slaughter, steers were measured ultrasonically by a Beef Improvement Federation (BIF, 1997) certified technician for fat thickness between the 12th and 13th ribs, 3/4 the length ventrally over the longissimus dorsi muscle (**UFAT**), and for longissimus muscle area between the 12th and 13th ribs (**UREA**). Images were also collected for rump fat thickness at the junction of the biceps femoris and gluteus medius muscles between the hook and pin bones parallel to the backbone (**URPFAT**), and for body wall thickness between the 12th and 13th ribs 4 cm ventral to the longissimus dorsi muscle, perpendicular to the external body surface (**UBDWALL**). Representative images are presented in Figures 1, 2, and 3. Images were taken with an Aloka 500V real-time ultrasound machine (Corometrics Medical Systems, Wallingford, CT) equipped with a 17.2 cm, 3.5 MHz linear transducer. To ensure proper contact between the ultrasound transducer and animal, the transducer was fitted with a Superflab (Mick Radio-Nuclear Instruments, Inc., Bronx, NY) guide for UFAT and UREA image collection. Hair was clipped and the area to be scanned thoroughly curried and cleaned prior to image collection. Vegetable oil was used as a couplant to obtain adequate acoustic contact. Once a suitable image had been obtained, the image was digitized and stored on a personal computer with a video frame grabber. Only one image per animal was stored for each ultrasound trait. Images were interpreted using software developed at Iowa State University.

Statistical analyses were conducted using SAS (1989). Pearson product moment correlation coefficients were used to evaluate the relationships between ultrasound and carcass measurements. Several variables were created to assess the accuracy of ultrasound measurements relative to carcass measurements:

$$\mathrm{FDIFF} = (\mathrm{UFAT} - \mathrm{CFAT})$$
$$\mathrm{FDEV} = |(\mathrm{UFAT} - \mathrm{CFAT})|$$
$$\mathrm{RDIFF} = (\mathrm{UREA} - \mathrm{CREA})$$
$$\mathrm{RDEV} = |(\mathrm{UREA} - \mathrm{CREA})|$$

Analysis of variance was also conducted for specific carcass measurement ranges so that accuracy of ultrasound measurements could be compared within the following six CFAT and five CREA categories:

CFAT <= .51 cm
CFAT > .51 and <= .76 cm
CFAT > .76 and <= 1.02 cm
CFAT > 1.02 and <= 1.27 cm
CFAT > 1.27 and <= .1.52 cm
CFAT > 1.52 cm

CREA <= 71.0 $cm^2$
CREA > 71.0 and <= 77.4 $cm^2$
CREA > 77.4 and <= 83.9 $cm^2$
CREA > 83.9 and <= 90.3 $cm^2$
CREA > 90.3 $cm^2$

Standard errors of prediction, adjusted for mean bias in the subclass of interest, were also calculated for UFAT and UREA. The standard error of prediction is a statistic used to evaluate ultrasound technician accuracy in current ultrasound certification clinics (BIF, 1997).

## Results and Discussion

Means and standard deviations for carcass and ultrasound measurements are presented in Table 1. The ranges for carcass measurements were: HCW 214 to 463 kg, CFAT .25 to 2.79 cm, and CREA 43.2 to 111.6 $cm^2$. The standard deviation for CFAT (.44 cm) is similar to those reported by Perkins et al. (1992b) and Herring et al. (1994) in recent accuracy papers. Since this study contained only steers, the CREA standard deviation (8.69 $cm^2$) is smaller than the 9.2 $cm^2$ reported by Perkins et al. (1992a) and 9.6 $cm^2$ reported by Duello (1992) who both utilized populations of mixed sexes.

Table 2 relates the correlation coefficients between carcass and ultrasound measures. The correlations between carcass and ultrasound measurements of 12-13th rib fat (.89) and longissimus muscle area (.86) are in agreement with values reported for experienced, highly skilled technicians. In a review of ultrasound accuracy studies, Houghton and Turlington (1992) report average correlations of .86 and .73 between carcass and ultrasound measurements of 12-13th rib fat and longissimus muscle area, respectively. However, the range of correlations for longissimus muscle area is generally more variable than 12-13th rib fat, although Robinson et al. (1992) reported mean longissimus muscle area correlations of .88 to .90 for technicians achieving accreditation at three clinics.

Although correlation coefficients are useful, they also have their limitations as they do not account for bias (tendency to underestimate or overestimate carcass measurement with ultrasound). Analysis of mean bias (FDIFF) revealed ultrasound underestimated CFAT .06 cm for the entire population (Table 1). This value is larger in magnitude but in the same direction as reported by Perkins et al. (1992a), Duello (1992), and Robinson et al. (1992). All studies reported that UFAT measurements are less than CFAT measurements. Mean FDEV indicated an average absolute difference between UFAT and CFAT of .16 cm. This value is similar to the results obtained by

Brethour (1992) (.157 cm) and Perkins et al. (1992a) (.19 cm), and is slightly lower than the .23 cm found by Duello (1992).

In contrast to fat thickness measurements, UREA measurements were larger (.71 $cm^2$) than CREA measurements in this study. In contrast, Smith et al. (1992) and Perkins et al. (1992b) reported the tendency for UREA to be smaller than CREA. The mean absolute difference between UREA and CREA (RDEV, Table 1) was 3.31 $cm^2$, which is more accurate than the range of 4.94 to 6.76 $cm^2$ reported by Herring et al. (1994) for technicians using a machine identical to what was used in the present study.

Analysis of variance revealed year to be a significant source of variation for ultrasound measurement variables. In 1995, mean FDIFF and FDEV were larger ($P < .01$) in magnitude compared to 1994. These differences may be partially attributed to differences in CFAT as steers were leaner ($P < .01$) in 1994 than 1995. Several studies have demonstrated that the magnitude of the difference between UFAT and CFAT increases as CFAT increases (Brethour, 1992; Duello, 1992; Herring et al., 1994). However, Table 4 reveals correlations between UFAT and CFAT were similar in 1994 ($r = .86$) and 1995 ($r = .90$).

Bias in ultrasound estimates of CREA was not different between years ($P > .10$), although RDIFF was smaller numerically in 1995. However, RDEV increased ($P < .01$) from 2.71 $cm^2$ in 1994 to 4.15 $cm^2$ in 1995, indicating that ultrasound estimates of CREA were more accurate in 1994. The stronger correlation between UREA and CREA in 1994 ($r = .91$ vs. .79 for 1995) reported in Table 4 supports this finding. The larger ($P < .01$) mean CREA in 1995 may have contributed to the larger RDEV as larger CREA have been shown to be estimated less accurately with ultrasound (Duello, 1992; Herring et al., 1994).

Most ultrasound accuracy studies to date have examined the effects of operator, machine, and animal sex. Few have reported on the effect of year using the same technician and machine on a population of similar cattle. Duello (1992) found year to year variation in ultrasound accuracy variables for both 12-13th rib fat and longissimus muscle area, although these effects could not be directly addressed since operator and machine were not consistent across the three year study. The differences in accuracy noted between years in this study may be due to technician error in collecting and interpreting images. Due to the length of this study, tendencies to deviate to one side or the other of anatomical reference points when interpreting UFAT and UREA may have resulted in the differences observed between years. It must also be stated that carcass measurements are not taken without error and this could have an effect on the perceived accuracy of ultrasound. As an example, Robinson et al. (1992) reported a difference of 1.3 $cm^2$ between two CREA tracers, presumably due to the tendency to deviate either to the inside or outside of the muscle boundary. Similarly, Rouse et al. (1992) obtained correlations of .97 for CFAT and .92 for CREA between two carcass evaluators. Therefore, there are evaluator differences in carcass measurements which may have implications to the year effects reported in this study.

The standard error of prediction is a statistic used in certification clinics to accreditate technicians for ultrasound proficiency (BIF, 1997). Robinson et al. (1992) states that this statistic has an advantage over mean absolute differences because by squaring differences, a few large errors are considered more serious than a greater number of small errors. The standard error of prediction is also thought to be the primary measure of the ability to correctly rank or predict differences between animals (Robinson et al., 1992).

The FSEP and RSEP overall and by year are presented in Table 5. Interestingly, FSEP was similar between years, although more bias (FDIFF) was introduced in 1995. Thus, after correction for bias, FSEP suggests that accuracy of measuring CFAT with ultrasound was similar for the two years. In contrast, RSEP is much smaller in 1994 than 1995 despite the smaller mean RDIFF obtained in 1995. The RSEP would indicate that CREA was more accurately estimated with ultrasound in 1994.

As a comparison, Robinson et al. (1992) reported ranges of .07 to .13 cm and 4.94 to 5.16 $cm^2$ for FSEP and RSEP, respectively, for technicians receiving accreditation. However, the cattle used by Robinson et al. (1992) had a mean CFAT of .45 cm, which is much leaner than reported in this study. Duello (1992) had a higher proportion of cattle with greater than 1.27 cm CFAT, and obtained overall FSEP and RSEP of .29 cm and 6.25 $cm^2$, respectively.

Earlier studies have questioned the use of ultrasound to assess CREA (Smith et al., 1992; Waldner et al., 1992). The low RSEP of 4.49 $cm^2$ achieved in the present study indicates ultrasound can be used to accurately identify differences in CREA between animals. The use of an ultrasonic transducer that allows the entire longissimus muscle to be imaged at once, compared to the split-screen technique required with shorter transducers used in earlier studies, likely contributed to this improvement in accuracy. Additionally, operator skill has been shown to have a strong influence on accuracy of ultrasonic estimation of carcass traits (Herring et al., 1994; Robinson et al., 1992; Waldner et al., 1992). The low FSEP and RSEP reported in Table 5 for this study further emphasize the accuracy achievable by an experienced, well trained technician. These values are appreciably smaller than the maximum .30 cm FSEP and 7.74 $cm^2$ RSEP established by the Beef Improvement Federation (1997) for technician certification.

To assess differences in the accuracy of ultrasound as a result of the magnitude of the carcass measures, the data set was divided into six categories based on CFAT and five categories based on CREA. Least squares means and standard errors of accuracy variables within these CFAT and CREA categories are presented in Tables 6 and 7, respectively. Means of FDIFF by CFAT category in Table 6 indicate that leaner cattle (< .51 cm CFAT) are overestimateed and fatter cattle (> 1.02 cm CFAT) are underestimateed with ultrasound. Least squares means of FDEV by CFAT category suggest the absolute difference between UFAT and CFAT is similar in categories with CFAT < 1.27 cm, increases slightly when CFAT is between 1.27 and 1.52 cm, and substantially increases when CFAT > 1.52 cm.

Similarly, RDIFF reported in Table 7 show ultrasound overestimates CREA in light muscled steers (< 77.4 $cm^2$ CREA), and underestimates CREA in heavy muscled steers (> 83.9 $cm^2$ CREA). Mean RDEV was largest for animals with very small (< 71.0 $cm^2$) and very large (> 90.3 $cm^2$) CREA. These results agree with previous studies that have examined bias of ultrasound measurements in different CFAT and CREA categories (Herring et al., 1994; Smith et al., 1992).

In contrast to the findings of Duello (1992), CFAT category influenced the accuracy of UREA. Table 6 suggests that ultrasound underestimates CREA in leaner cattle (< .51 cm CFAT) and has the opposite effect in fatter cattle (> 1.27 cm CFAT). Additionally, RDEV tended to increase as CFAT increased. These results would support the theory that increased subcutaneous fat cover makes it more difficult to obtain a clear, high quality image, particularly in the lower left portion of the image (Figure 1). As a result, determination of longissimus muscle boundaries becomes difficult and therefore reduces the accuracy of the ultrasound measurement.

Standard errors of prediction by CFAT and CREA category are presented in Table 8. These results generally agree with the DIFF and DEV variables previously discussed. Although the differences are small, FSEP tended to increase as CFAT increased. RSEP were greatest in steers with CREA < 71 and > 90.3 $cm^2$, with the smallest RSEP observed for the 83.9 to 90.3 $cm^2$ CREA category. The increase in RSEP as magnitude of CFAT increased further supports the idea that accurate assessment of longissimus muscle area becomes more difficult in cattle with more fat cover.

Also of interest in this study was the characterization of URPFAT and UBDWALL, which have been identified as additional measurements that may be useful in predicting beef carcass composition (Cross et al., 1973; Wallace et al., 1977; Williams et al., 1997). Means and ranges for URPFAT and UBDWALL were 1.09 cm (.30 to 2.29 cm) and 5.36 cm (3.34 to 8.43 cm), respectively (Table 1). Table 2 indicates that both URPFAT and UBDWALL are positively related to CFAT and UFAT. As with CFAT and UFAT, mean URPFAT and UBDWALL measurements increased ($P < .01$) from 1994 to 1995 (Table 3). Table 4 suggests the correlations of URPFAT with CFAT and UFAT were consistent across year. However, UBDWALL was more strongly related to both CFAT and UFAT in 1994 than 1995. The reason for this difference is not known, however it is possible that there may have been some inconsistencies in image interpretation that occurred between years such as those discussed earlier for UFAT and UREA. The correlation between URPFAT and UBDWALL (.44) indicate these two traits are moderately related.

Presented in Table 9 are least squares means and standard errors of URPFAT and UBDWALL by CFAT category. Results indicate that both traits increase as both CFAT and UFAT increase. Of interest is the mean URPFAT compared to CFAT and UFAT for each category. In cattle with < 1.02 cm CFAT, URPFAT mean exceeded both CFAT and UFAT. It has been proposed that URPFAT could serve as an alternative measurement site for subcutaneous fat in leaner cattle (breeding cattle), since URPFAT is greater than CFAT and therefore differences between animals could more easily be measured with ultrasound. Data presented in Table 9 support this idea.

Since rump fat measurements are difficult to obtain on the carcass, accuracy measures for URPFAT are not available in this study. Robinson et al. (1992) reported rump fat depth measured with ultrasound to be consistently 20% higher than carcass measurements, and accuracy measures for rump fat were similar to those found for 12-13th rib fat. The ultrasonic rump fat measure used by Robinson et al. (1992) was at the P8 site, which is similar to but not the precise location used for URPFAT in this study. The P8 site does not have an obvious reference point, whereas the rump fat site in the present study uses a muscle junction (Figure 2) to ensure consistent placement of the transducer.

## Implications

Results from this study indicate that ultrasound technology has the potential to determine fat thickness and longissimus muscle area with a high degree of accuracy when done by an experienced, well trained technician. Therefore, ultrasound can be used to describe carcass traits in live cattle and allow for selection and management decisions to made. Differences in accuracy for ultrasonic measurements across years emphasize the importance of proper maintenance of technique by technicians, and the need for periodic proficiency testing. The strong relationship between ultrasonic measurements of rump fat and body wall thickness with carcass 12-13th rib fat thickness suggest the need for further investigation of these variables as additional indicators of composition.

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Table 1. Means and standard deviations of carcass and ultrasound measures (n = 534)

| Trait | Mean | SD |
|---|---|---|
| HCW, kg | 342.5 | 41.9 |
| CFAT, cm | 1.09 | .44 |
| UFAT, cm | 1.02 | .35 |
| CREA, $cm^2$ | 78.10 | 8.69 |
| UREA, $cm^2$ | 78.81 | 7.62 |
| URPFAT, cm | 1.09 | .32 |
| UBDWALL, cm | 5.36 | .82 |
| FDIFF, cm | -.06*** | .20 |
| FDEV, cm | .16 | .14 |
| RDIFF, $cm^2$ | .71*** | 4.49 |
| RDEV, $cm^2$ | 3.39 | 3.03 |

***Mean values different from zero (P < .001).

Table 2. Correlation coefficients among ultrasound and carcass measurements (n = 534)

| Variable | CFAT | UFAT | CREA | UREA | URPFAT | UBDWALL |
|---|---|---|---|---|---|---|
| CFAT | 1.00 | .89*** | -.14*** | -.04 | .61*** | .53*** |
| UFAT | | 1.00 | -.20*** | -.09* | .70*** | .57*** |
| CREA | | | 1.00 | .86*** | -.09* | .14*** |
| UREA | | | | 1.00 | -.02 | .24*** |
| URPFAT | | | | | 1.00 | .44*** |
| UBDWALL | | | | | | 1.00 |

*Values different from zero (P < .05).
***Values different from zero (P < .001).

Table 3. Means and standard deviations of carcass and ultrasound measures by year

| | 1994 (n = 282) | | 1995 (n = 252) | |
|---|---|---|---|---|
| Trait | Mean | SD | Mean | SD |
| HCW, kg | 333.6 | 40.4 | 352.4 | 41.4 |
| CFAT, cm | 1.04 | .41 | 1.14 | .46 |
| UFAT, cm | 1.00 | .35 | 1.05 | .35 |
| CREA, $cm^2$ | 75.99 | 7.99 | 80.45 | 8.83 |
| UREA, $cm^2$ | 77.04 | 7.49 | 80.79 | 7.27 |
| URPFAT, cm | 1.04 | .32 | 1.15 | .32 |
| UBDWALL, cm | 5.21 | .75 | 5.53 | .86 |
| FDIFF, cm | -.04*** | .19 | -.09*** | .21 |
| FDEV, cm | .15 | .13 | .18 | .14 |
| RDIFF, $cm^2$ | 1.05*** | 3.35 | .34 | 5.48 |
| RDEV, $cm^2$ | 2.71 | 2.22 | 4.15 | 3.68 |

***Mean values different from zero (P < .001).

Table 4. Correlation coefficients between ultrasound and carcass measurements by year

| Variable | CFAT | UFAT | CREA | UREA | URPFAT | UBDWALL |
|---|---|---|---|---|---|---|
| | | | | 1994 (n = 282) | | |
| CFAT | 1.00 | .86*** | -.21*** | -.13* | .59*** | .57*** |
| UFAT | | 1.00 | -.25*** | -.16** | .69*** | .62*** |
| CREA | | | 1.00 | .91*** | -.14* | .07 |
| UREA | | | | 1.00 | -.10† | .15* |
| URPFAT | | | | | 1.00 | .43*** |
| UBDWALL | | | | | | 1.00 |
| | | | | 1995 (n = 252) | | |
| CFAT | 1.00 | .90*** | -.15* | -.01 | .63*** | .48*** |
| UFAT | | 1.00 | -.21*** | -.06 | .72*** | .52*** |
| CREA | | | 1.00 | .79*** | -.14* | .12* |
| UREA | | | | 1.00 | -.03 | .25*** |
| URPFAT | | | | | 1.00 | .42*** |
| UBDWALL | | | | | | 1.00 |

†Values different from zero (P < .10).
*Values different from zero (P < .05).
**Values different from zero (P < .01).
***Values different from zero (P < .001).

Table 5. Standard errors of prediction for ultrasound measures of carcass traits

| | n | FSEP, cm | RSEP, $cm^2$ |
|---|---|---|---|
| 1994 | 282 | .19 | 3.35 |
| 1995 | 252 | .21 | 5.48 |
| Overall | 534 | .20 | 4.49 |

Table 6. Least squares means and standard errors of accuracy variables by fat category

| CFAT category | n | FDIFF, cm | FDEV, cm | RDIFF, $cm^2$ | RDEV, $cm^2$ |
|---|---|---|---|---|---|
| <= .51 cm | 58 | $.106 \pm .022^{d}$ | $.138 \pm .017^{ab}$ | $-.91 \pm .53^{a}$ | $2.87 \pm .39^{a}$ |
| > .51 & <= .76 cm | 121 | $.038 \pm .015^{c}$ | $.125 \pm .012^{a}$ | $-.14 \pm .37^{ab}$ | $3.44 \pm .27^{ab}$ |
| > .76 & <= 1.02 cm | 123 | $-.045 \pm .015^{c}$ | $.125 \pm .012^{a}$ | $.12 \pm .37^{ab}$ | $3.56 \pm .27^{ab}$ |
| > 1.02 & <= 1.27 cm | 109 | $-.127 \pm .016^{b}$ | $.159 \pm .012^{bc}$ | $.11 \pm .40^{ab}$ | $3.64 \pm .29^{ab}$ |
| > 1.27 & <= 1.52 cm | 56 | $-.160 \pm .023^{b}$ | $.185 \pm .017^{c}$ | $1.13 \pm .57^{bc}$ | $4.22 \pm .41^{bc}$ |
| > 1.52 cm | 67 | $-.307 \pm .021^{a}$ | $.299 \pm .016^{d}$ | $1.46 \pm .51^{c}$ | $4.47 \pm .37^{c}$ |

[a,b,c,d,e]Means in a column with different superscripts differ ($P < .05$).

Table 7. Least squares means and standard errors of accuracy variables by longissimus muscle area category

| CREA category | n | RDIFF, $cm^2$ | RDEV, $cm^2$ |
|---|---|---|---|
| <= 71.0 $cm^2$ | 92 | 3.42±.43[a] | 4.26±.31[f] |
| > 71.0 & <= 77.4 $cm^2$ | 168 | 1.69±.32[b] | 3.10±.23[g] |
| > 77.4 & <= 83.9 $cm^2$ | 144 | .55±.34[c] | 2.93±.25[g] |
| > 83.9 & <= 90.3 $cm^2$ | 81 | -1.56±.46[d] | 2.99±.34[g] |
| > 90.3 $cm^2$ | 49 | -2.61±.59[d] | 5.22±.43[e] |

[a,b,c,d]Means in a column with different superscripts differ (P < .05).
[e,f,g]Means in a column with different superscripts differ (P < .10).

Table 8. Standard errors of prediction by 12-13th rib fat and longissimus muscle area categories

| Category | n | FSEP, cm | RSEP, $cm^2$ |
|---|---|---|---|
| CFAT | | | |
| <= .51 cm | 58 | .16 | 3.75 |
| > .51 & <= .76 cm | 121 | .16 | 4.36 |
| > .76 & <= 1.02 cm | 123 | .15 | 4.21 |
| > 1.02 & <= 1.27 cm | 109 | .17 | 4.49 |
| > 1.27 & <= 1.52 cm | 56 | .18 | 4.25 |
| > 1.52 cm | 67 | .20 | 5.26 |
| CREA | | | |
| <= 71.0 $cm^2$ | 92 | .20 | 4.83 |
| > 71.0 & <= 77.4 $cm^2$ | 168 | .21 | 3.82 |
| > 77.4 & <= 83.9 $cm^2$ | 144 | .22 | 3.79 |
| > 83.9 & <= 90.3 $cm^2$ | 81 | .18 | 2.86 |
| > 90.3 $cm^2$ | 49 | .16 | 5.52 |

Table 9. Least squares means and standard errors of rump fat and body wall thickness by fat category

| CFAT category | n | CFAT, cm | UFAT, cm | URPFAT, cm | UBDWALL, cm |
|---|---|---|---|---|---|
| <= .51 cm | 58 | $.47\pm.014^{a}$ | $.58\pm.022^{a}$ | $.76\pm.033^{a}$ | $4.65\pm.089^{g}$ |
| > .51 & <= .76 cm | 121 | $.73\pm.010^{b}$ | $.76\pm.015^{b}$ | $.93\pm.023^{b}$ | $5.02\pm.063^{h}$ |
| > .76 & <= 1.02 cm | 123 | $.97\pm.010^{c}$ | $.93\pm.015^{c}$ | $1.06\pm.023^{c}$ | $5.32\pm.062^{i}$ |
| > 1.02 & <= 1.27 cm | 109 | $1.23\pm.010^{d}$ | $1.10\pm.016^{d}$ | $1.15\pm.025^{d}$ | $5.56\pm.066^{j}$ |
| > 1.27 & <= 1.52 cm | 56 | $1.47\pm.015^{e}$ | $1.31\pm.023^{e}$ | $1.32\pm.035^{e}$ | $5.93\pm.095^{k}$ |
| > 1.52 cm | 67 | $1.92\pm.013^{f}$ | $1.61\pm.021^{f}$ | $1.44\pm.032^{f}$ | $6.20\pm.086^{l}$ |

$^{a,b,c,d,e,f}$Means in a column with different superscripts differ ($P < .01$).
$^{g,h,i,j,k,l}$Means in a column with different superscripts differ ($P < .05$).

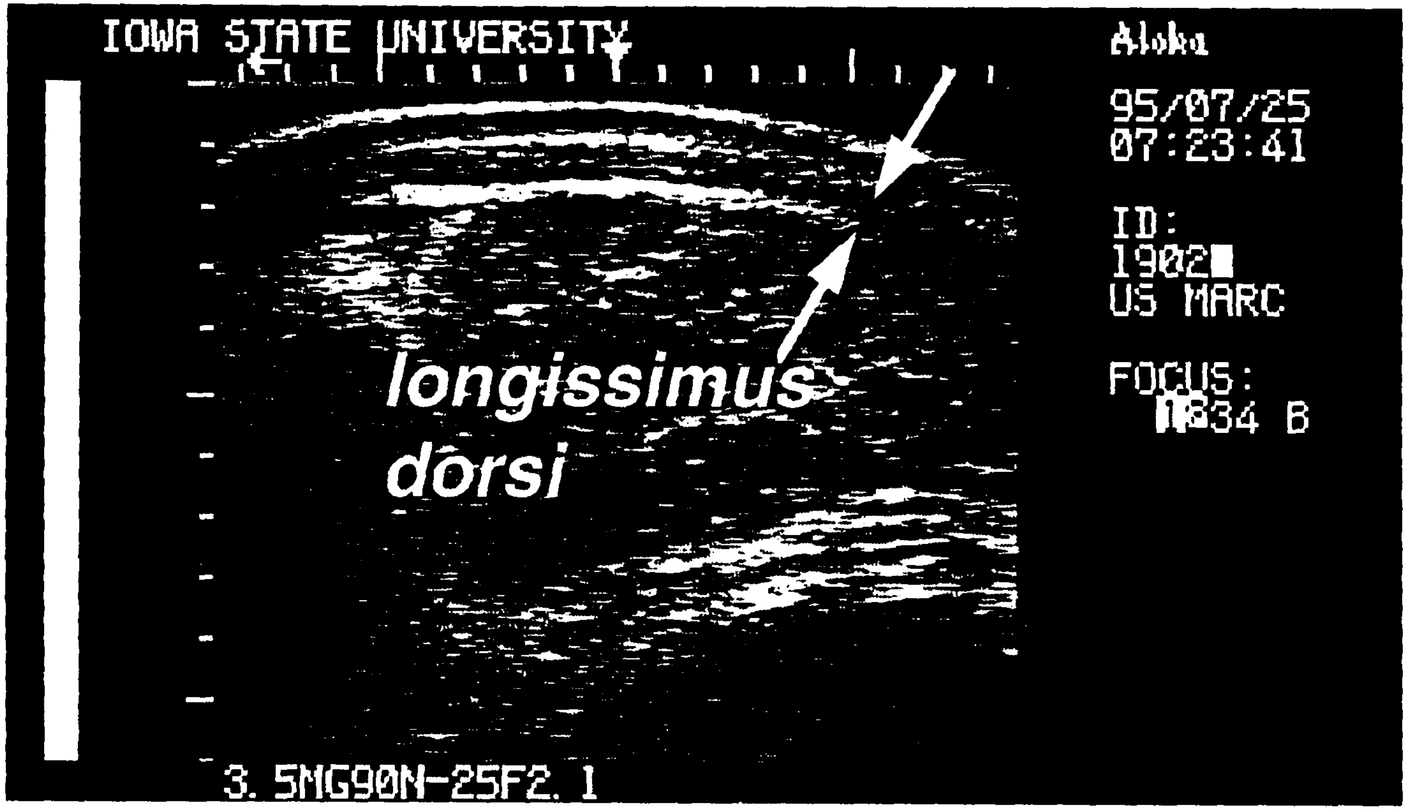


Figure 1. Real-time ultrasound image collected between the 12th and 13th ribs

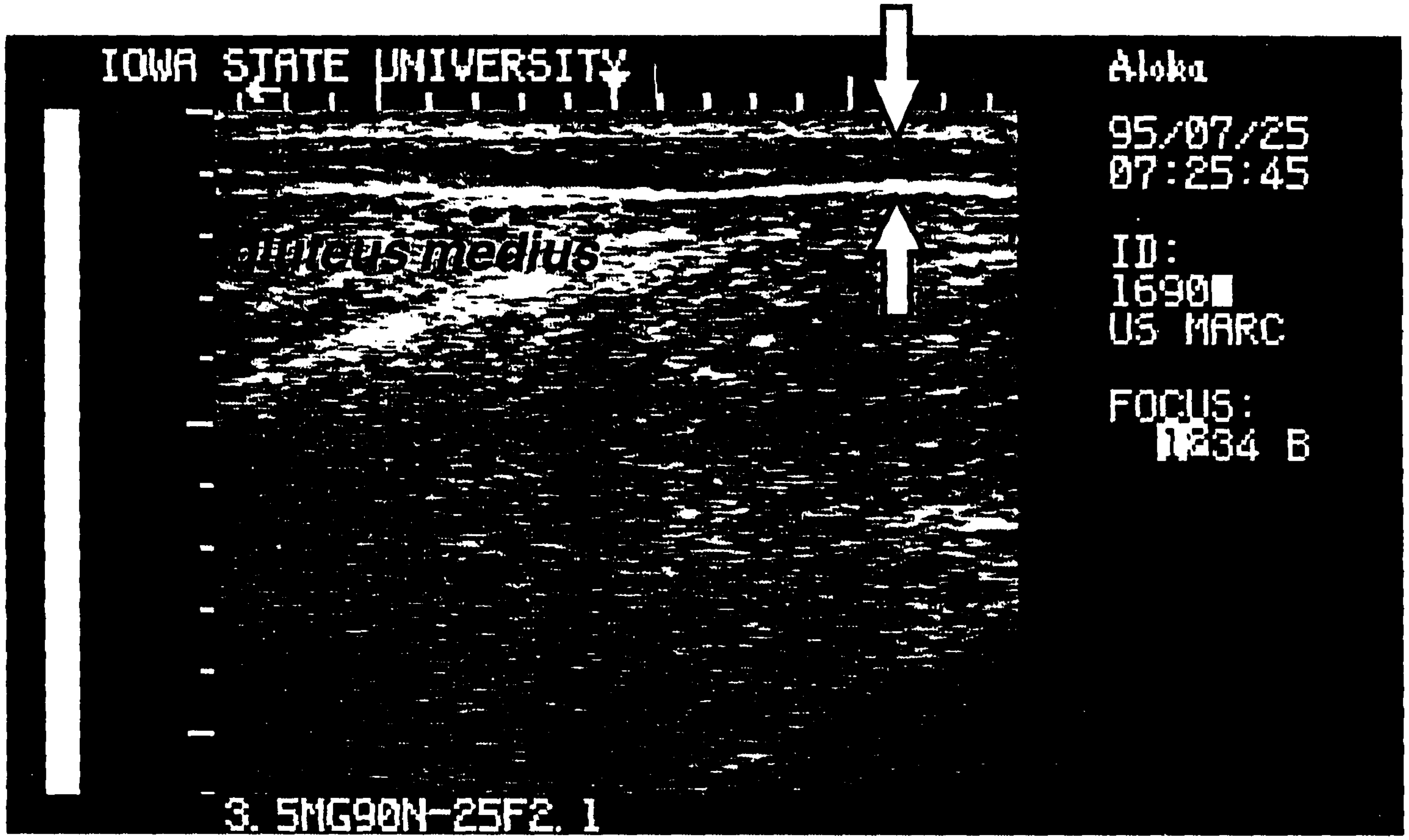


Figure 2. Real-time ultrasound image collected for measuring rump fat thickness

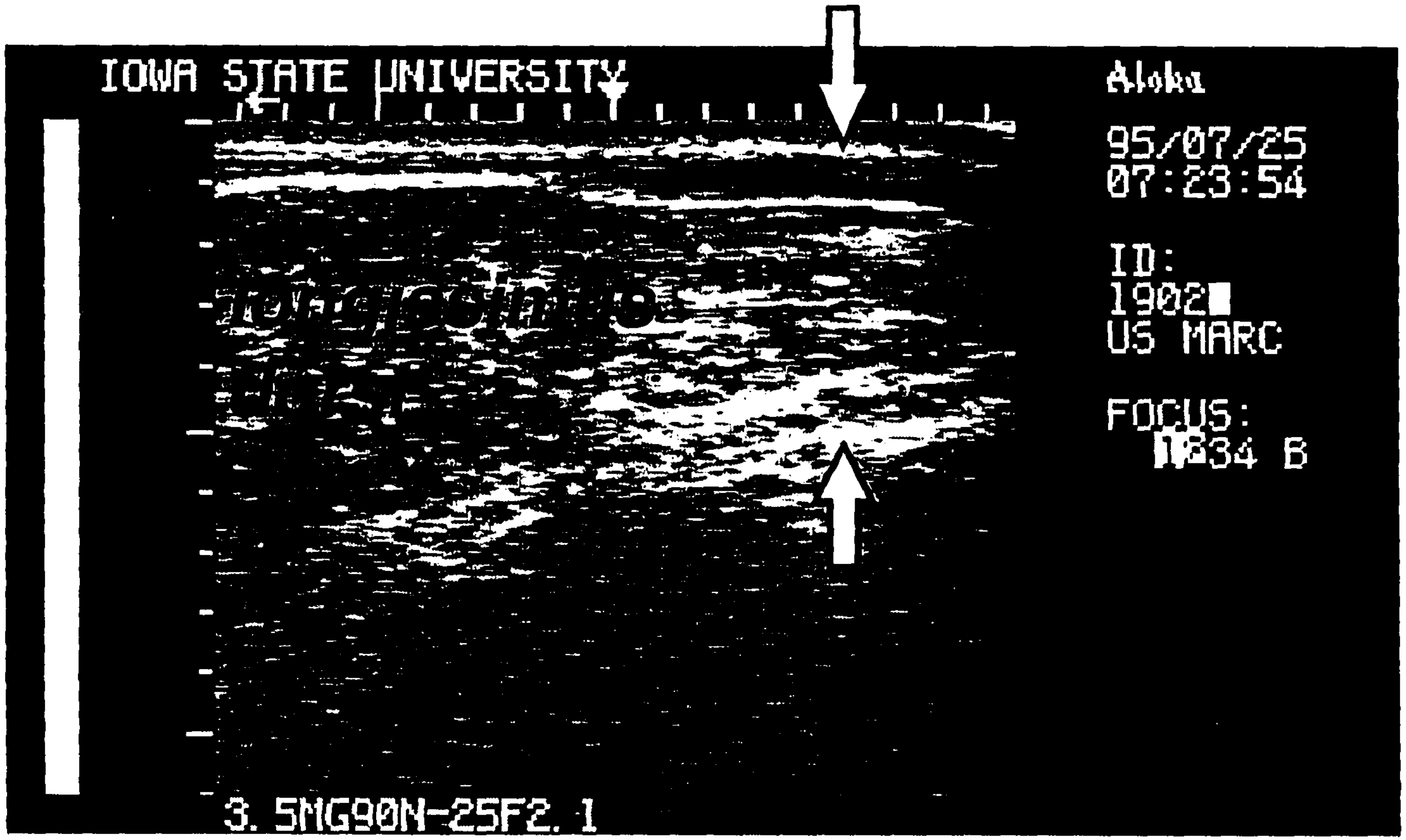


Figure 3. Real-time ultrasound image collected for measuring body wall thickness

# PREDICTION OF RETAIL PRODUCT WEIGHT AND PERCENTAGE USING REAL-TIME ULTRASOUND AND CARCASS MEASUREMENTS IN BEEF CATTLE

A paper to be submitted to the Journal of Animal Science

S. P. Greiner[1], G. H. Rouse[1], D. E. Wilson[1], L. V. Cundiff[2], and T. L. Wheeler[2]

**Abstract**

Data from five hundred thirty-four steers representing 6 sire breed groups was used to develop live animal ultrasound prediction equations for weight and percentage of retail product. Steers were ultrasonically measured for 12-13th rib fat thickness (UFAT), rump fat thickness (URPFAT), longissimus muscle area (UREA), and body wall thickness (UBDWALL) within 5 d prior to slaughter. Carcass measurements included in USDA yield grade (YG) and quality grade calculation were obtained. Carcasses were fabricated into boneless, totally trimmed retail product. Regression equations to predict weight (KGRPRD) and percentage (PRPRD) of retail product were developed using either live animal or carcass traits as independent variables. Most of the variation in KGRPRD was accounted for by live weight (FWT) and carcass weight with $R^2$ values of .66 and .69, respectively. Fat measurements accounted for the largest

[1]Department of Animal Science, Iowa State University, Ames, IA 50011.
[2]Roman L. Hruska U.S. Meat Animal Research Center, ARS, USDA, Clay Center, NE 68933.

portion of the variation in PRPRD when used as single predictors ($R^2$ = .54, .44, .23, and .54 for UFAT, URPFAT, UBDWALL, and carcass fat, respectively). Final models ($P < .10$) using live animal variables included FWT, UFAT, UREA, and URPFAT for KGRPRD ($R^2$ = .84) and UFAT, URPFAT, UREA, UBDWALL, and FWT for PRPRD ($R^2$ = .61). Comparatively, equations using YG variables resulted in $R^2$ values of .86 and .65 for KGRPRD and PRPRD, respectively. These results indicate that live animal equations using ultrasound measurements are nearly as predictive of beef carcass composition as carcass measurements.

## Introduction

Real-time ultrasound has been shown to be an accurate predictor of carcass 12-13th rib fat thickness and longissimus muscle area in beef cattle (Robinson et al., 1992; Duello, 1993). Ultrasound technology has also been used to predict beef carcass retail yield. In a study using 180 steers representing 11 sire-breed groups, Hamlin et al. (1995) reported ultrasonic measurements of fat thickness and longissimus muscle area combined with live weight accounted for 61 to 64% of the variation in percentage of retail product. To aid in the prediction of beef carcass composition, alternative ultrasonic sites to 12-13th rib fat thickness and longissimus muscle area have been investigated. Wallace et al. (1977) reported a correlation of -.53 between ultrasonic rump fat thickness and retail yield, and Miller et al. (1988) showed rump fat thickness can account for a large portion of the variation in carcass fat. Williams et al. (1997)

showed the addition of rump fat to live animal predictors of yield grade components increased the $R^2$ value .14 for predicting percentage of retail product. Furthermore. Cross et al. (1973) reported correlations of .41 and -.61 between carcass body wall thickness with weight and percentage of retail cuts, respectively. Perkins et al. (1992) found ultrasound body wall thickness to relate to carcass fat and lean parameters. The objective of this study was to examine the efficacy of using traditional ultrasonic measures of 12-13th rib fat and longissimus muscle area, along with ultrasonic rump fat and body wall thickness, to predict weight and percentage of beef carcass retail product in a large number of steers that had considerable variation in carcass composition.

## Materials and Methods

This study was conducted in cooperation with the Roman L. Hruska U.S. Meat Animal Research Center (**MARC**). Clay Center, NE. Five hundred thirty-four calf-fed steers from the 1993 (n = 282) and 1994 (n = 252) calf crops of Cycle V of the Germ Plasm Evaluation (**GPE**) program were used. Cycle V $F_1$ calves were produced by mating Hereford, Angus, and MARC III (1/4 Red Poll, 1/4 Hereford, 1/4 Pinzgauer, 1/4 Angus) dams to Hereford, Angus, Tuli, Boran, Belgian Blue, and Brahman bulls.

Steers were fed a corn-corn silage diet from weaning to slaughter. The growing diet contained 2.7 Mcal ME/kg DM and 12.9% CP and the finishing diet fed from approximately 320 kg to slaughter contained 3.04 Mcal ME/kg DM and 10.9% CP. Beginning in mid-May, representative samples of steers (balanced across breed groups) were slaughtered serially in slaughter groups spaced approximately 21 d apart. Data used in this study includes all 4 slaughter groups in 1994 and the final 3 slaughter groups in 1995. Steers were slaughtered at a commercial packing facility, and following a 24 h chill carcasses were evaluated for USDA yield and quality grade factors (USDA, 1989) by MARC personnel.

Within 5 d prior to slaughter, steers were measured ultrasonically by a Beef Improvement Federation (BIF, 1997) certified technician for fat thickness between the 12th and 13th ribs, 3/4 the length ventrally over the longissimus dorsi muscle (**UFAT**), and for longissimus muscle area between the 12th and 13th ribs (**UREA**). Images were also collected for rump fat thickness at the junction of the biceps femoris and gluteus medius muscles between the hook and pin bones parallel to the backbone (**URPFAT**), and for body wall thickness between the 12th and 13th ribs 4 cm ventral to the longissimus dorsi muscle, perpendicular to the external body surface (**UBDWALL**). Images were taken with an Aloka 500V real-time ultrasound machine (Corometrics Medical Systems, Wallingford, CT) equipped with a 17.2 cm, 3.5 MHz linear transducer. To ensure proper contact between the ultrasound transducer and animal, the transducer was fitted with a Superflab (Mick Radio-Nuclear Instruments, Inc., Bronx, NY) guide for UFAT and UREA image collection. Hair was clipped and the area to be scanned thoroughly curried and cleaned prior to image collection. Vegetable oil was used as a couplant to obtain adequate acoustic contact. Once a suitable image had been obtained, the image was digitized and stored on a personal computer with a video frame grabber. Only one image per animal was stored for each ultrasound trait. Images were interpreted using software developed at Iowa State University. A final live weight (**FWT**) and hip height (**HT**) were also obtained.

The right side of each carcass was transported to MARC for fabrication into boneless, totally trimmed retail product. Sides were cut into wholesale and subprimal cuts trimmed to 0 cm of fat, lean trim, fat trim, and bone as described by Wheeler et al. (1997). Chemical fat content was used to adjust the lean trim to 20% fat. Weights of boneless, totally trimmed retail cuts and 20% fat lean trim were summed to give retail product weight (**KGRPRD**). Percentage of retail product (**PRPRD**) was calculated by dividing retail product weight by the sum of the parts (retail product weight + fat trim weight + bone weight) x 100.

Statistical analyses were conducted using SAS (1989). Pearson product-moment correlations were estimated between live animal and carcass traits with kilograms and percentage of retail product. Prediction product moment equations were developed by stepwise regression procedures using either live animal or carcass traits as independent variables. Independent variables had to be significant ($P < .10$) to remain in models. Equations were evaluated with respect to $R^2$, root mean square error (**RMSE**), and Cp as described by Mallows (1973). For models with a close fit, Cp approaches the number of predictor variables (MacNeil, 1983). Genetic and environmental effects were not considered in the modeling process.

Prediction equations using carcass measurements were developed as a comparison to equations developed using live animal measurements. Measurements of adjusted fat thickness (**ACFAT**), longissimus muscle area (**CREA**), estimated percentage of kidney, pelvic, and heart fat (**CKPH**), hot carcass weight (**HCW**), and marbling score (**MARB**) were used to develop carcass prediction equations.

## Results and Discussion

Means, SD, and ranges for live animal and carcass traits are reported in Table 1. The sire breeds used in the GPE study resulted in a large amount of variation in carcass cutability with PRPRD ranging from 53.7 to 75.8% and USDA yield grade from 1.25 to 6.11. Mean age at slaughter was 448.4 d, with a range of 383 to 501 d. Carcasses averaged 343 kg, 1.01 cm, and 78.1 $cm^2$ for HCW, ACFAT, and CREA, respectively.

Presented in Table 2 are simple correlation coefficients between carcass and live animal traits with KGRPRD and PRPRD. Weight and muscle variables had the strongest relationships with KGRPRD, ranging from .61 for UREA to .83 for HCW. Carcass variables had higher correlations with KGRPRD than the corresponding traits measured in the live animal (.83 vs. .81 for weight, and .68 vs. .61 for REA). In contrast, when retail product was expressed as a percentage, variables describing weight had negative correlations while those describing longissimus muscle area had positive correlation estimates. Measurements of 12-13th rib fat thickness had small, but significant negative relationships with KGRPRD (-.12 and -.10 for ACFAT and UFAT, respectively), whereas URPFAT and UBDWALL had either nonsignificant ($P > .10$) or small correlations with KGRPRD.

Measures of fat (ACFAT, CKPH, UFAT, URPFAT, UBDWALL) had negative correlations with PRPRD. The highest correlation with PRPRD was found for UFAT ($r = -.74$), which is stronger than the correlations reported for unadjusted or ACFAT (-.68 and -.73, respectively). The higher correlation for ACFAT vs. unadjusted carcass fat thickness reflects necessary adjustments made for uneven distribution of fat and disruption of the fat layer over the longissimus dorsi muscle during hide pulling and other processing. Measurements of fat had stronger correlations with PRPRD than measurements of muscle. Alternative ultrasonic fat measurement sites (URPFAT and UBDWALL) were also highly related to PRPRD. Williams et al. (1997) reported URPFAT to account for a larger portion of the variation in PRPRD than UFAT. Miller et al. (1988), Wallace et al. (1977), and others have shown rump fat thickness to be useful in predicting percentage of carcass fat. In the present study, UFAT had the strongest relationship with PRPRD. Cross et al. (1973) reported a correlation of -.61 between carcass body wall thickness and percentage of retail cuts. A similar correlation of -.48 was found in this study when body wall thickness was estimated ultrasonically.

Several researchers have developed equations for predicting weight and percentage of retail product using carcass and live animal measurements (Murphy et al., 1960; Fitzhugh et al., 1965; Cross et al., 1973; Crouse and Dikeman, 1976; Parrett et al., 1985, Herring et al., 1994; Williams et al., 1997). Regression equations for predicting weight and percentage of retail product from live animal measurements are presented in Table 3. Most of the variation in PRPRD was explained by UFAT with an $R^2$ value of .54 when fit alone (data not shown). URPFAT was the second variable to enter into the model using stepwise regression ($R^2$ = .44 alone), and together UFAT and URPFAT accounted for 58% of the variation in PRPRD (Equation 1). Variability in KGRPRD was largely attributed to differences in FWT, resulting in an $R^2$ value of .66 when used as a single predictor (data not shown).

Researchers have found 12-13th rib fat thickness to be the best measurement for predicting beef carcass retail product yield (Crouse and Dikeman, 1976; Abraham et al., 1980). In addition, other measurement sites for fat in both the live animal and carcass have been shown to be useful for predicting composition in beef cattle (Williams et al., 1997; Wallace et al., 1977). In the present study, both UFAT and URPFAT were significant variables in equations when retail product was expressed on a weight or percentage basis. Ultrasonic 12-13th rib fat thickness was the first fat measurement variable to enter into the stepwise regression modeling process for prediction of both PRPRD and KGRPRD. This is in contrast to Williams et al. (1997), who reported rump fat to be superior to 12-13th rib fat in predicting retail yield from live animal measures. In the present study, URPFAT accounted for an additional 4% of the variation in PRPRD when used with UFAT (Equation 1). Alone, UFAT and URPFAT explained less than 5% of the variation in KGRPRD. However, inclusion of UFAT with FWT (Equation 7) increased the $R^2$ value from .66 to .78 compared to using FWT alone to predict KGRPRD. Although a significant ($P < .10$) variable for prediction of KGRPRD (Equation 9), URPFAT explained < 1% additional variation after FWT, UFAT, and UREA had been included in the model.

Carcass body wall thickness has been reported to be related to both percentage and weight of retail cuts (Brungardt and Bray, 1963; Cross et al., 1973). In the present study, UBDWALL was a significant variable in prediction of PRPRD but not KGRPRD. However, UBDWALL only improved the $R^2$ from .60 to .61 when included with UFAT, URPFAT, and UREA to predict PRPRD (Equation 2 vs. 5). This is in agreement with Perkins et al. (1992) who reported ultrasonic body wall thickness added little predictive power for retail yield beyond 12th rib fat thickness and longissimus muscle area. Furthermore, Abraham et al. (1980) found body wall thickness measured 10.2 cm from the lateral end of the longissimus dorsi muscle to be a significant variable for prediction of percentage of retail cuts, but concluded improvement in cutability equations when added to yield grade variables did not warrant its inclusion.

Ultrasound longissimus muscle area was a significant variable in equations to predict both PRPRD and KGRPRD. Addition of UREA to UFAT and URPFAT explained an additional 1.4% of the variation in PRPRD (Equation 1 vs. 2), and an additional 4.3% of the variation for KGRPRD when included with FWT and UFAT (Equation 7 vs. 8). Hamlin et al. (1995) reported longissimus muscle area measured with ultrasound to offer little improvement in $R^2$ value (0 to .03) in models for predicting percentage of retail product after inclusion of a fat and weight measurement.

Similarly, Herring et al. (1994) and Wallace et al. (1977) reported that neither ultrasound longissimus muscle area nor carcass longissimus muscle area improved prediction equations for weight or percentage of retail product. Corresponding to the results of the present study, Williams et al. (1997) found UREA to be a significant variable in live animal equations developed for prediction of both weight and percentage of retail product. Crouse et al. (1975) concluded that inclusion of longissimus muscle area may be useful to account for variation in cutability associated with breed groups due to a strong relationship between breed group means for cutability and longissimus muscle area. Researchers have found longissimus muscle area is a better indicator of weight than percentage of retail product (Hedrick et al., 1965; Abraham et al., 1968; Epley et al., 1970). When used as a single predictor in the current study, UREA accounted for more of the variation in KGRPRD than PRPRD ($R^2 = .38$ vs. .03).

Final live weight accounted for 66% of the initial variation in KGRPRD, with the remaining 16% of the variation accounted for by UFAT, UREA, and URPFAT. In contrast, FWT was the last variable to enter stepwise prediction equations for PRPRD. Herring et al. (1994) and Williams et al. (1997) reported live weight was not a significant variable in prediction equations developed for percentage of retail product using live animal measures. Although FWT was significant ($P < .10$) in the present study, comparison of Equations 5 and 6 reveal FWT resulted in minimal improvement in $R^2$ and RMSE after UFAT, URPFAT, UREA, and UBDWALL had been fit.

As a comparison, prediction equations for PRPRD and KGRPRD using carcass measurements are shown in Table 4. Equations including USDA yield grade variables resulted in $R^2$ values of .65 and .86 for PRPRD and KGRPRD, respectively (Equations 12 and 16). Inclusion of MARB explained an additional 3% of the variation in PRPRD (Equation 13). When used alone, MARB was second only to ACFAT in explaining variation in PRPRD ($R^2$ = .27), and was the second variable to be included in prediction equations using stepwise analysis (data not shown). This is in agreement with Kauffman et al. (1975) who reported marbling score to be superior to both kidney, pelvic, and heart fat and carcass weight in accounting for variation in percent fat-free muscle. Furthermore, Crouse and Dikeman (1976) reported correlations between marbling score and percentage of retail product of -.38 within breeds and -.48 across breed groups, and found marbling score to be useful as a predictor of percentage of retail product.

The best models using live animal measurements had similar $R^2$ values to models including carcass measurements currently used in USDA equations when predicting percentage (.61, Equation 6 vs. .65, Equation 12) or weight (.84, Equation 9 vs. .86, Equation 16) of retail product. Hamlin et al. (1995), in a study using 180 steers from 11 sire-breed groups, reported $R^2$ values of .61 to .64 using live animal measures as predictors of retail yield, and concluded ultrasound-based equations were 10% less predictive of beef carcass retail yield than carcass-based equations. Faulkner et al. (1990), Bullock et al. (1991), Herring et al. (1994), and Williams et al. (1997) have found ultrasound measurements combined with other live animal variables to be as predictive as carcass measures for beef carcass composition. Herring et al. (1994) reported an $R^2$ value of .34 using UFAT and visual fatness score to predict percentage of closely trimmed retail product. Using similar ultrasound and live measures to those in the present study, Williams et al. (1997) reported an $R^2$ of .32 for retail product yield (.32 cm fat trim). The higher $R^2$ values achieved in the present study for PRPRD (.58 to .61) may be the result of more variation in cutability and carcass traits due to the sire breeds used in Cycle V, compared to Herring et al. (1994) and Williams et al. (1997) who utilized populations of similar breed composition slaughtered at a pen average fat thickness endpoint as determined by ultrasound. However, for retail product weight Herring et al. (1994) and Williams et al. (1997) reported $R^2$ values of .82 to .87 using live animal measures, which are similar to those found in this study ($R^2$ = .78 to .84).

As a single predictor, UFAT was equal to ACFAT in explaining initial variation in PRPRD ($R^2$ = .54 for both). In contrast, the $R^2$ value for unadjusted carcass fat thickness used alone to predict PRPRD was .47. Due to the absence of disruptive processing factors such as hide removal, fat thickness measured on the live animal using ultrasound may be as accurate as ACFAT for estimating the true amount of 12-13th rib subcutaneous fat.

Despite a strong correlation between CREA and UREA (r = .86), CREA was more highly related to retail product weight and percentage. Carcass longissimus muscle area accounted for 46% of the variation in KGRPRD compared to 37% for

UREA when fit alone. Similarly, CREA explained 6.5% more of the variation in PRPRD than UREA when each variable was used as a single predictor ($R^2$ = .093 vs. .028). It appears from the present study that ultrasonic measurements of fat thickness may be more predictive than carcass measures for retail product yield, whereas longissimus muscle area measured on the carcass is more highly related to retail yield parameters than ultrasonic longissimus muscle area.

Equation 3 uses ultrasound measurements of UFAT and UREA along with FWT to predict PRPRD. The $R^2$ value for this equation is lower than that reported for Equations 1 and 2, which include UFAT and URPFAT or these two variables along with UREA. It appears from the present study that two ultrasound fat measurements (UFAT and URPFAT) used in combination are more accurate and precise estimators of PRPRD than the combined traditional measures of UFAT, UREA, and FWT. Inclusion of URPFAT with UFAT, UREA, and FWT accounted for an additional 3% of the variation in PRPRD (Equation 3 vs. 4).

The higher $R^2$ values reported for KGRPRD using carcass variables compared to live animal measurements are largely due to the difference in initial variation explained by HCW vs. FWT. As a single predictor, HCW explained 3% more of the initial variation in KGRPRD than FWT. In fact, when HCW was used along with UFAT to predict weight of retail product, the resulting $R^2$ value was the same (.83) as that for Equation 14 which uses HCW and ACFAT. Furthermore, substitution of FWT with HCW in Equations 7 through 9 increased coefficients of determination from .01 to .04

(data not shown). Therefore, differences in dressing percentage may account for a large portion of the differences in $R^2$ values between carcass and live animal equations for predicting KGRPRD.

## Implications

This research indicates that live animal ultrasound measurements are useful predictors of retail yield. Alternative measurements of rump fat and body wall thickness are made possible with ultrasound technology, and enhanced the predictive capability of live animal-based equations for retail yield. Rump fat improved prediction equations for percentage of retail product when used along with live weight and traditional ultrasonic measurements of 12-13th rib fat thickness and longissimus muscle area. The relative ease with which this measurement may be taken further justifies its inclusion. Although body wall thickness was found to be a significant variable in equations for retail yield, little additional variation was explained. Further investigation and refinement of this measurement are needed. Live animal prediction equations using ultrasound measurements will enhance genetic evaluation programs for carcass traits.

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Table 1. Simple statistics for live animal and carcass traits

| Trait | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Live | | | | |
| Age, d | 448.4 | 24.0 | 383.0 | 501.0 |
| FWT, kg | 555.0 | 63.6 | 354.3 | 760.8 |
| UFAT, cm | 1.02 | .35 | .23 | 2.06 |
| UREA, $cm^2$ | 78.8 | 7.6 | 59.3 | 104.0 |
| URPFAT, cm | 1.09 | .32 | .30 | 2.29 |
| UBDWALL, cm | 5.36 | .82 | 3.34 | 8.43 |
| HT, cm | 133.2 | 4.6 | 113.0 | 146.7 |
| Carcass | | | | |
| HCW, kg | 342.5 | 41.9 | 214.4 | 462.9 |
| Unadjusted fat thickness, cm | 1.09 | .44 | .25 | 2.79 |
| ACFAT, cm | 1.01 | .42 | .25 | 2.54 |
| CREA, $cm^2$ | 78.1 | 8.7 | 43.2 | 111.6 |
| CKPH, % | 2.96 | .61 | 1.00 | 5.00 |
| USDA yield grade | 3.08 | .73 | 1.25 | 6.11 |
| MARB[a] | 503.8 | 62.0 | 350.0 | 770.0 |
| KGRPRD, kg | 103.5 | 12.8 | 72.2 | 144.1 |
| PRPRD, % | 64.2 | 4.2 | 53.7 | 75.8 |

[a]300 = Traces$^0$, 400 = Slight$^0$, 500 = Small$^0$, 600 = Modest$^0$, 700 = Moderate$^0$.

Table 2. Simple correlations of traits with weight and percentage of retail product

| Trait | KGRPRD | PRPRD |
|---|---|---|
| FWT | .81*** | -.26*** |
| UFAT | -.10* | -.74*** |
| UREA | .61*** | .17*** |
| URPFAT | .03 | -.66*** |
| UBDWALL | .11* | -.48*** |
| HT | .63*** | -.11* |
| HCW | .83*** | -.26*** |
| Unadjusted fat thickness | -.08† | -.68*** |
| ACFAT | -.12** | -.73*** |
| CREA | .68*** | .31*** |
| CKPH | .05 | -.40*** |
| USDA yield grade | -.06 | -.79*** |
| MARB | -.04 | -.52*** |

†Values different from zero ($P < .1$).

*Values different from zero ($P < .05$).

**Values different from zero ($P < .01$).

***Values different from zero ($P < .001$).

Table 3. Equations for predicting weight and percentage of retail product from live animal measurements

| Dependent variable and equation | $R^2$ | RMSE | Cp | Partial regression coefficients: Intercept | UFAT, cm | URPFAT, cm | UREA, $cm^2$ | UBDWALL, cm | FWT, kg |
|---|---|---|---|---|---|---|---|---|---|
| PRPRD | | | | | | | | | |
| 1 | .58 | 2.74 | 39.78 | 74.92 | -6.486 | -3.722 | | | |
| 2 | .60 | 2.70 | 23.80 | 69.78 | -6.283 | -3.841 | .064 | | |
| 3 | .57 | 2.79 | 63.67 | 70.41 | -8.227 | | .093 | | -.009 |
| 4 | .60 | 2.68 | 20.39 | 70.67 | -6.185 | -3.513 | .083 | | -.005 |
| 5 | .61 | 2.66 | 9.37 | 70.82 | -5.297 | -3.750 | .088 | -.745 | |
| 6 | .61 | 2.65 | 6.00 | 71.71 | -5.201 | -3.423 | .107 | -.744 | -.005 |
| KGRPRD | | | | | | | | | |
| 7 | .78 | 5.98 | 163.11 | 14.25 | -13.568 | | | | .186 |
| 8 | .83 | 5.34 | 24.64 | -6.37 | -11.514 | | .403 | | .162 |
| 9 | .84 | 5.24 | 5.00 | -6.01 | -8.718 | -4.811 | .390 | | .167 |

Table 4. Equations for predicting weight and percentage of retail product from carcass measurements

| Dependent variable and equation | $R^2$ | RMSE | Cp | Partial regression coefficients: Intercept | ACFAT, cm | CKPH, cm | CREA, $cm^2$ | HCW, kg | MARB[a] |
|---|---|---|---|---|---|---|---|---|---|
| PRPRD | | | | | | | | | |
| 10 | .57 | 2.76 | 164.65 | 75.07 | -6.727 | -1.372 | | | |
| 11 | .62 | 2.62 | 96.59 | 67.18 | -6.241 | -1.608 | .104 | | |
| 12 | .65 | 2.52 | 49.71 | 68.83 | -5.472 | -1.417 | .165 | -.023 | |
| 13 | .68 | 2.42 | 6.00 | 74.20 | -4.897 | -1.300 | .149 | -.018 | -.013 |
| KGRPRD | | | | | | | | | |
| 14 | .83 | 5.38 | 185.53 | 16.81 | -11.615 | | | .287 | |
| 15 | .85 | 4.95 | 76.45 | 3.79 | -9.418 | | .308 | .249 | |
| 16 | .86 | 4.77 | 34.79 | 7.12 | -8.574 | -2.325 | .315 | .255 | |
| 17 | .87 | 4.64 | 6.00 | 15.60 | -7.668 | -2.141 | .289 | .262 | -.020 |

[a]300 = Traces$^0$, 400 = Slight$^0$, 500 = Small$^0$, 600 = Modest$^0$, 700 = Moderate$^0$.

# ACCURACY OF PREDICTING WEIGHT AND PERCENTAGE OF BEEF CARCASS RETAIL PRODUCT USING REAL-TIME ULTRASOUND AND LIVE ANIMAL MEASURES

A paper to be submitted to the Journal of Animal Science

S. P. Greiner[1], G. H. Rouse[1], D. E. Wilson[1], L. V. Cundiff[2], and T. L. Wheeler[2]

## Abstract

Five hundred thirty-four steers were evaluated over a two year period to develop and test prediction equations for estimating carcass composition from live animal ultrasound measurements and to compare these equations with those developed from carcass measurements. Within 5 d prior to slaughter, steers were ultrasonically measured for 12-13th rib fat (UFAT), longissimus muscle area (UREA), rump fat thickness (URPFAT), and body wall thickness (UBDWALL). Carcasses were fabricated to determine boneless, totally trimmed retail product weight (KGRPRD) and percentage (PRPRD). Data from steers born in 1993 (n = 282) were used to develop prediction equations using stepwise regression. Final models using live animal variables included live weight (FWT), UFAT, UREA, and URPFAT for KGRPRD ($R^2$ = .83) and UFAT, URPFAT, UREA, FWT, and UBDWALL for PRPRD ($R^2$ = .67).

[1]Department of Animal Science, Iowa State University, Ames, IA 50011.
[2]Roman L. Hruska U.S. Meat Animal Research Center, ARS, USDA, Clay Center, NE, 68933.

Equations developed from USDA yield grade variables resulted in $R^2$ values of .87 and .68 for KGRPRD and PRPRD, respectively. When these equations were applied to steers born in 1994 (n = 252), correlations between values predicted from live animal models and actual carcass values were .92 for KGRPRD, and ranged from .73 to .76 for PRPRD. Similar correlations were found for equations developed from carcass measures (r = .94 for KGRPRD and .81 for PRPRD). Both live animal and carcass equations overestimated ($P < .01$) actual KGRPRD and PRPRD. Regression of actual values on predicted values revealed a similar fit for equations developed from live animal and carcass measures. This research indicates that composition prediction equations developed from live animal and ultrasound measurements can be useful to estimate carcass composition.

## Introduction

The use of real-time ultrasound to predict carcass traits in live beef cattle has been evaluated by several workers, and found to be an accurate predictor of carcass 12-13th rib fat thickness and longissimus muscle area (Duello, 1993; Robinson et al., 1992; Herring et al., 1994a). Due to this relationship, equations using a combination of ultrasound and live animal measures have been developed to predict beef carcass composition and have shown the potential to be as accurate as models developed from carcass measurements (Herring et al., 1994b; Williams et al., 1997). In addition, measurements such as rump fat thickness that are made possible with ultrasound and are difficult to obtain on the carcass may enhance the capability of live animal prediction equations (Wallace et al., 1977; Williams et al., 1997).

However, recent published reports on the validation of live animal prediction equations are rare due to the expense of carcass fabrication. Faulkner et al. (1990) developed equations for cow composition, and reported the efficacy of live measurements to be similar to that of carcass measurements when applied to an independent set of animals. Herring et al. (1994b) reported models using live animal traits ranked animals equally as well as carcass equations and the USDA cutability equation for retail yield. For live animal prediction equations to be widely used by the beef industry to enhance beef improvement programs or evaluate slaughter cattle, the utility of live animal equations for predicting carcass composition must be investigated.

Therefore, the objective of this study was to develop prediction equations for weight and percentage of retail product from live animal and carcass measurements and to test the accuracy of these equations when applied to another data set.

## Materials and Methods

This study was conducted in cooperation with the Roman L. Hruska U.S. Meat Animal Research Center (**MARC**), Clay Center, NE. Five hundred thirty-four calf-fed steers from the 1993 (n = 282) and 1994 (n = 252) calf crops of Cycle V of the Germ Plasm Evaluation (**GPE**) program were used. Cycle V $F_1$ calves were produced by mating Hereford, Angus, and MARC III (1/4 Red Poll, 1/4 Hereford, 1/4 Pinzgauer, 1/4 Angus) dams to Hereford, Angus, Tuli, Boran, Belgian Blue, and Brahman bulls.

Steers were fed a corn-corn silage diet from weaning to slaughter. The growing diet contained 2.7 Mcal ME/kg DM and 12.9% CP and the finishing diet fed from approximately 320 kg to slaughter contained 3.04 Mcal ME/kg DM and 10.9% CP. Beginning in mid-May, representative samples of steers (balanced across breed groups) were slaughtered serially in slaughter groups spaced approximately 21 d apart. Data used in this study includes all 4 slaughter groups in 1994 and the final 3 slaughter groups in 1995. Steers were slaughtered at a commercial packing facility. Following a 24 h chill, carcasses were evaluated for USDA yield and quality grade factors (USDA, 1989) by MARC personnel.

Within 5 d prior to slaughter, steers were measured ultrasonically by a Beef Improvement Federation (BIF, 1997) certified technician for fat thickness between the 12th and 13th ribs, 3/4 the length ventrally over the longissimus dorsi muscle (**UFAT**), and for longissimus muscle area between the 12th and 13th ribs (**UREA**). Images were also collected for rump fat thickness at the junction of the biceps femoris and gluteus medius muscles between the hook and pin bones parallel to the backbone (**URPFAT**), and for body wall thickness between the 12th and 13th ribs 4 cm ventral to the longissimus dorsi muscle, perpendicular to the external body surface (**UBDWALL**). Images were taken with an Aloka 500V real-time ultrasound machine (Corometrics Medical Systems, Wallingford, CT) equipped with a 17.2 cm, 3.5 MHz linear transducer. To ensure proper contact between the ultrasound transducer and animal, the transducer was fitted with a Superflab (Mick Radio-Nuclear Instruments, Inc., Bronx, NY) guide for UFAT and UREA image collection. Hair was clipped and the area to be scanned thoroughly curried and cleaned prior to image collection. Vegetable oil was used as a couplant to obtain adequate acoustic contact. Once a suitable image had been obtained, the image was digitized and stored on a personal computer with a video frame grabber. Only one image per animal was stored for each ultrasound trait. Images were interpreted using software developed at Iowa State University. A final live weight (**FWT**) and hip height (**HT**) were also obtained.

The right side of each carcass was transported to MARC for fabrication into boneless, totally trimmed retail product. Sides were cut into wholesale and subprimal cuts trimmed to 0 cm of fat, lean trim, fat trim, and bone as described by Wheeler et al. (1997). Chemical fat content was used to adjust the lean trim to 20% fat. Weights of boneless, totally trimmed retail cuts and 20% fat lean trim were summed to give retail product weight (**KGRPRD**). Percentage of retail product (**PRPRD**) was calculated by dividing retail product weight by the sum of the parts (retail product weight + fat trim weight + bone weight) x 100.

Statistical analyses were conducted using SAS (1989). The data was split by year, with data from the 1993-born steers used to develop linear multiple regression models to predict percentage and kilograms of retail product. Prediction equations were developed by stepwise regression procedures using either live animal or carcass traits as independent variables. Measurements of adjusted fat thickness (**ACFAT**), longissimus muscle area (**CREA**), estimated percentage of kidney, pelvic, and heart fat (**CKPH**), hot carcass weight (**HCW**), and marbling score (**MARB**) were used to develop carcass prediction equations. Independent variables had to be significant ($P < .10$) to remain in models. Equations were evaluated with respect to coefficient of determination (**$R^2$**), root mean square error (**RMSE**), and Cp as described by Mallow (1973). For models with a close fit, Cp approaches the number of predictor variables (MacNeil, 1983). Genetic and environmental effects were not considered in the modeling process.

Data from the 1994 calf crop was used to validate and test the accuracy of the prediction equations developed. All equations were tested on every animal in the validation set. The statistics evaluated to compare the validation results from the different prediction equations included the validation RMSE, $R^2$, and the intercept and slope of the regression between the actual and predicted values for retail yield of steers in the validation set. Correlation coefficients between predicted and actual values were also computed. Bias and absolute residuals were calculated for each prediction equation.

## Results and Discussion

Means, standard deviations, minimum, and maximum values of live animal and carcass traits used in equation development and validation are presented in Tables 1 and

2, respectively. The variation in carcass and live animal traits reflects the diversity of the sire breeds used in Cycle V of the GPE study. For model development, the PRPRD mean was 65.2 ± 4.3%, and the KGRPRD mean was 102.6 ± 12.8 kg. Mean PRPRD (63.1 ± 3.9%) was lower and KGRPRD (104.5 ± 12.9 kg) was higher for steers used in model validation. Since data for this study were not available for the first slaughter group of the 1994 calf crop (validation set), means for fat measurements, weight, and REA were higher for the model validation than the development set. However, variation in live animal and carcass traits as well as trait ranges were similar for the model development and validation sets.

Regression equations for predicting PRPRD and KGRPRD from live animal measurements are presented in Table 3. The majority of the variation in PRPRD was explained by UFAT, with an $R^2$ value of .59 when fit alone. In addition to UFAT, URPFAT measurements have been shown to be valuable live animal predictors of retail yield (Williams et al., 1997). In the present study, URPFAT was the second variable to enter into the model using stepwise regression ($R^2$ = .44 alone), and together UFAT and URPFAT accounted for 63% of the variation in PRPRD (data not shown). Of interest was the inclusion of an additional ultrasonic fat measurement, UBDWALL, which has been shown to be related to percentage and weight of retail product when measured on the carcass (Brungardt and Bray, 1963; Cross et al., 1973). Although UBDWALL had a strong relationship with PRPRD (r = -.49), it was the last variable to be included in prediction equations for PRPRD developed from stepwise regression (Equation 3).

Final live weight accounted for the majority of the variation in KGRPRD ($R^2$ = .63 alone), and combined with UFAT explained 77% of the variability in kilograms of retail product (data not shown). Inclusion of UREA (Equation 4) increased the $R^2$ value .05, and reduced RMSE .79 kg. The final model for prediction of KGRPRD using live animal variables included FWT, UFAT, UREA, and URPFAT (Equation 5).

Prediction equations for PRPRD and KGRPRD using carcass traits as independent variables are presented in Table 4. Equations 6 and 8 utilize carcass yield grade traits as predictors. The best live animal equations for PRPRD and KGRPRD (Equations 3 and 5) were similar in their predictive power ($R^2$) to yield grade trait-based carcass equations (Equations 6 and 8). Researchers have also reported marbling score to be a useful predictor of carcass composition (Kauffman et al., 1973; Crouse and Dikeman, 1976). In the present study, MARB explained an additional 4% of the variation in PRPRD when included with yield grade variables (Equation 6 vs. 7), and it was a significant variable for KGRPRD prediction (Equation 9).

Table 5 reports the mean PRPRD predicted by the various live animal and carcass equations. All equations overestimated ($P < .01$) actual PRPRD. Means for bias and absolute residual between Equations 3 and 6 and between Equations 3 and 7 were not different ($P > .10$), suggesting that the best live animal model (Equation 3) was as accurate as carcass variable models (Equations 6 and 7) for estimating PRPRD. Correlation coefficients between actual and predicted values of PRPRD ranged from .73 to .76 for live animal equations and were .80 and .81 for carcass equations. As a comparison, the correlation between YG and PRPRD for the validation set was -.79 (data not shown).

Reports that deal concurrently with model development and validation are limited. The USDA cutability equation derived from the regression equation by Murphy et al. (1960) has been the most widely tested on independent populations of beef carcasses. Generally, the USDA equation has been an acceptable predictor of actual yields, with correlation coefficients ranging from .73 to .85 (Brackelsberg and Willham, 1968; Cross et al., 1973; Crouse et al., 1975). Although carcass fabrication procedures are different, correlation coefficients in the present study between actual and predicted retail yield using live animal equations ($r = .73$ to .76) are similar to those generally reported for the USDA equation.

Validation statistics for KGRPRD are also reported in Table 5. As with PRPRD, both live animal and carcass equations overestimated actual KGRPRD ($P < .01$). Mean bias for live animal Equation 5 was lower ($P < .01$) than for carcass Equations 8 and 9. Absolute residual means between the best live animal (Equation 5) and carcass (Equations 8 and 9) equations were not different ($P > .10$), suggesting that the average amount of error introduced by live animal and carcass prediction equations was similar. Additionally, correlation coefficients between actual and predicted KGRPRD ranged from .92 to .94, and were similar for equations derived from either live animal or carcass variables.

Herring et al. (1994b) compared rank correlations between predicted values for PRPRD and KGRPRD using equations developed from live animal and ultrasound traits, carcass traits, and the USDA cutability equation. Models using live animal traits ranked the animals as well as carcass models and the USDA equation for retail yield, while live animal and carcass equations ranked animals equally for weight of retail product. Correlations for this study reported in Table 5 follow a similar trend.

Analysis of the regression of predicted values on observed values for PRPRD and KGRPRD are given in Tables 6. An unbiased prediction model should result in an intercept not different from zero and a slope not different from one (MacNeil, 1983). In the present study, as more variables were included in live animal or carcass equations, a greater degree of fit was exhibited as intercept and slope values more closely approached zero and one, respectively. Equation 3 exhibited the greatest degree of fit for live animal models, and accounted for 57% of the actual variation in PRPRD. In comparison, the best carcass equation (Equation 7) accounted for 66% of the variation in actual PRPRD.

Carcass equations for KGRPRD (Equations 8 and 9) exhibited intercepts that were not different from zero ($P > .10$) and slopes that were very close to one, indicating a good model fit. Live animal equations accounted for 84% of the variation in actual KGRPRD, whereas carcass equations accounted for 88% (Table 6). Carcass weight and live weight have been shown to be the best single predictors of retail product weight for carcass and live animal equations, respectively (Epley et al., 1970; Williams et al., 1997). Therefore, some of the differences noted between live animal and carcass equations for KGRPRD may be due to animal variation in dressing percentage.

Faulkner et al. (1990) developed prediction equations for various cow composition traits using live animal and carcass variables. When tested on an independent set of animals, live animal equations (including live weight, 12th rib ultrasound fat, and hip height) for percentage of fat and kilograms of fat-free lean exhibited the greatest degree of fit when observed carcass values were regressed on predicted values. In agreement with the results reported in Table 6, Faulkner et al. (1990) found $R^2$ values were similar for live and carcass estimates of composition.

Residual distribution may be a better indicator of model fit than correlations between predicted and actual values, as correlations do not account for bias. Cumulative frequency analysis for Equation 3, which includes all live animal measurements, indicated 34.1% of the predicted observations had residuals smaller than ±1%, 51.6% smaller than ±2%, and 71.4% smaller than ±3%. Carcass Equation 6 had 34.9, 56.4, and 71.0% of residuals smaller than ±1, 2, and 3%, respectively. For all equations, the largest number of predicted observations had residuals ±.5%.

Cumulative frequency distributions of the residuals for KGRPRD equations were also evaluated. Live animal Equation 5 had 31.4% of the observations with residuals smaller than ±2 kg, 61.5% smaller than ±4 kg, and 79.0% smaller than ±6 kg. As with PRPRD, KGRPRD residual frequency distributions were similar for live animal and carcass equations. However, carcass Equation 8 had the highest percentage of residuals within ±1, 2, 3, and 4 kg.

Predicted values for PRPRD, mean bias, absolute residual means, and correlations between actual and predicted values for PRPRD are reported in Table 7 for animals with low (<61%), medium (61 to 65%), and high (>65%) PRPRD. Results indicate that both live animal and carcass equations overestimated actual PRPRD in the low and medium retail yield categories. Mean bias and absolute residual means were larger in magnitude for the low cutability group as compared to the medium and high retail yield groups. Correlation coefficients between actual and predicted values were also lower in the low retail yield category. Live animal equations underestimated actual PRPRD in the high retail yield category, whereas carcass equations overestimated actual PRPRD. Absolute residual means were lowest in the high retail yield category for both carcass and live animal models. Correlation coefficients between actual and predicted values ranged from .55 to .57 for the medium retail yield category, and were .72 in the high retail yield category for carcass trait equations.

Hedrick and Krause (1975) reported similar trends when actual retail yields of 590 steer carcasses were compared to predicted yields determined by the USDA cutability equation. Predicted retail yields of low cutability (< 50%) steer carcasses exceeded actual retail yields 1.20%, whereas predicted retail yields of high cutability carcasses (> 55%) were 3.49% less than actual values.

Retail yield categories were also defined for KGRPRD, and associated statistics are reported in Table 8. Mean bias revealed overestimation for both live animal and carcass equations for steers having less than 98 kg or from 98 to 111 kg retail product. Live animal equations underestimated actual value for animals with greater than 111 KGRPRD, whereas carcass equations overestimated in this category. Absolute residual means were similar across retail yield categories for live animal equations, while absolute residual means tended to decrease with additional KGRPRD for carcass-based models.

The ability of an equation developed from ultrasound and live animal traits to predict percentage or weight of carcass retail product equally as well as those developed from carcass measures is dependent upon the accuracy of the ultrasound measures. Several studies have shown that ultrasound has a tendency to overestimate carcass 12-13th rib fat thickness in leaner cattle and underestimate this same trait in fatter cattle (Duello, 1992; Herring et al., 1994a; Robinson et al., 1992). Since 12-13th rib fat is the most important predictor and is inversely related to retail yield (Abraham et al., 1980; Crouse and Dikeman, 1976), measurement bias with ultrasound would likely result in overestimation of retail yield in low cutability cattle and underestimation of retail yield in high cutability cattle such as that reported in this study.

Equation 3, which includes UFAT, URPFAT, UREA, FWT, and UBDWALL appears to be the best live animal model for prediction of PRPRD based upon the various validation statistics. Inclusion of alternative ultrasound fat measurement sites

(URPFAT and UBDWALL) improved the accuracy and precision of models compared to traditional live animal measurements of UFAT. UREA. and FWT (Equation 1).

## Implications

Results from this research indicate live animal prediction equations developed from ultrasonic measurements are similar in their predictive power and accuracy for weight and percentage of beef carcass retail product when compared to equations developed from carcass measurements. Ultrasonic measurement of rump fat and body wall thickness. two measurements that are easy to obtain on the live animal. added to the predictive capability of traditional ultrasound measures of 12-13th rib fat and longissimus muscle area. Application of live animal prediction models that successfully predict carcass composition in slaughter progeny and breeding animals will allow for rapid genetic progress and enable producers to be competitive in a value-based marketing system.

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Table 1. Simple statistics for live animal and carcass traits used in model development

| Trait | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Live | | | | |
| Age, d | 441.6 | 24.7 | 383.0 | 494.0 |
| FWT, kg | 547.9 | 63.7 | 354.3 | 731.3 |
| UFAT, cm | 1.00 | .35 | .23 | 2.01 |
| UREA, $cm^2$ | 77.0 | 7.5 | 59.3 | 102.2 |
| URPFAT, cm | 1.04 | .32 | .36 | 2.29 |
| UBDWALL, cm | 5.21 | .75 | 3.34 | 7.46 |
| HT, cm | 132.6 | 4.7 | 113.0 | 144.8 |
| Carcass | | | | |
| HCW, kg | 333.6 | 40.4 | 214.4 | 450.1 |
| Unadjusted fat thickness, cm | 1.04 | .41 | .25 | 2.79 |
| ACFAT, cm | .98 | .41 | .25 | 2.54 |
| CREA, $cm^2$ | 76.0 | 8.0 | 58.7 | 100.0 |
| CKPH, % | 2.78 | .60 | 1.00 | 4.50 |
| USDA yield grade | 3.04 | .71 | 1.25 | 5.46 |
| MARB[a] | 501.2 | 63.5 | 350.0 | 690.0 |
| KGRPRD, kg | 102.6 | 12.8 | 72.2 | 138.2 |
| PRPRD, % | 65.2 | 4.3 | 55.0 | 75.8 |

[a]300 = Traces$^0$, 400 = Slight$^0$, 500 = Small$^0$, 600 = Modest$^0$, 700 = Moderate$^0$.

Table 2. Simple statistics for live animal and carcass traits used in model validation

| Trait | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Live | | | | |
| Age, d | 455.9 | 21.0 | 400.0 | 501.0 |
| FWT, kg | 563.0 | 62.7 | 397.9 | 760.8 |
| UFAT, cm | 1.05 | .35 | .41 | 2.06 |
| UREA, $cm^2$ | 80.8 | 7.3 | 62.5 | 104.0 |
| URPFAT, cm | 1.15 | .32 | .30 | 2.06 |
| UBDWALL, cm | 5.53 | .86 | 3.56 | 8.43 |
| HT, cm | 133.9 | 4.3 | 121.9 | 146.7 |
| Carcass | | | | |
| HCW, kg | 352.4 | 41.4 | 247.1 | 462.9 |
| Unadjusted fat thickness, cm | 1.14 | .46 | .25 | 2.54 |
| ACFAT, cm | 1.05 | .44 | .25 | 2.29 |
| CREA, $cm^2$ | 80.5 | 8.8 | 43.2 | 111.6 |
| CKPH, % | 3.17 | .55 | 1.50 | 5.00 |
| USDA yield grade | 3.12 | .75 | 1.37 | 6.11 |
| MARB[a] | 506.9 | 60.4 | 390.0 | 770.0 |
| KGRPRD, kg | 104.5 | 12.9 | 75.8 | 144.1 |
| PRPRD, % | 63.1 | 3.9 | 53.7 | 74.7 |

[a]300 = Traces$^0$, 400 = Slight$^0$, 500 = Small$^0$, 600 = Modest$^0$, 700 = Moderate$^0$.

Table 3. Prediction equations for weight and percentage of retail product developed from live animal measurements

| Dependent variable and equation | $R^2$ | RMSE | Cp | Partial regression coefficients: Intercept | UFAT, cm | URPFAT, cm | UREA, $cm^2$ | FWT, kg | UBDWALL, kg |
|---|---|---|---|---|---|---|---|---|---|
| PRPRD | | | | | | | | | |
| 1 | .64 | 2.60 | 25.50 | 69.32 | -8.502 | | .135 | -.011 | |
| 2 | .66 | 2.53 | 8.88 | 69.69 | -6.893 | -2.936 | .121 | -.007 | |
| 3 | .67 | 2.51 | 6.00 | 70.83 | -6.033 | -2.913 | .138 | -.008 | -.598 |
| KGRPRD | | | | | | | | | |
| 4 | .82 | 5.42 | 14.88 | -6.05 | -11.430 | | .461 | .154 | |
| 5 | .83 | 5.30 | 4.00 | -5.39 | -8.597 | -5.170 | .437 | .161 | |

Table 4. Prediction equations for weight and percentage of retail product developed from carcass measurements

| | | | | Partial regression coefficients | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dependent variable and equation | $R^2$ | RMSE | Cp | Intercept | ACFAT, cm | CREA, $cm^2$ | HCW, kg | CKPH, % | MARB[a] |
| PRPRD | | | | | | | | | |
| 6 | .68 | 2.45 | 43.67 | 66.21 | -6.101 | .202 | -.024 | -.823 | |
| 7 | .72 | 2.29 | 6.00 | 72.94 | -5.494 | .172 | -.018 | -.614 | -.016 |
| KGRPRD | | | | | | | | | |
| 8 | .87 | 4.62 | 31.66 | 3.12 | -9.225 | .356 | .256 | -1.465 | |
| 9 | .88 | 4.41 | 6.00 | 13.91 | -8.251 | .308 | .267 | -1.130 | -.025 |

[a]300 = Traces$^0$, 400 = Slight$^0$, 500 = Small$^0$, 600 = Modest$^0$, 700 = Moderate$^0$.

Table 5. Validation statistics for retail product equations

| Equation | Predicted value | Bias[a] | Absolute residual | Correlation of actual and predicted value[a] |
|---|---|---|---|---|
| Live animal | | | | |
| 1 | 65.09% | 1.94% | 2.65% | .73 |
| 2 | 64.87% | 1.72% | 2.49% | .75 |
| 3 | 64.79% | 1.63% | 2.42% | .76 |
| 4 | 106.11 kg | 1.57 kg | 4.34 kg | .92 |
| 5 | 105.73 kg | 1.19 kg | 4.28 kg | .92 |
| Carcass | | | | |
| 6 | 64.88% | 1.73% | 2.34% | .80 |
| 7 | 64.90% | 1.75% | 2.36% | .81 |
| 8 | 107.83 kg | 3.29 kg | 4.27 kg | .94 |
| 9 | 107.87 kg | 3.33 kg | 4.27 kg | .94 |

[a]Values different from zero ($P < .01$).

Table 6. Regression of predicted values on actual values for retail product equations

| Equation | Intercept | $b_1$ | $R^2$ | RMSE |
|---|---|---|---|---|
| Live animal | | | | |
| 1 | 8.02±3.24 | .85±.05 | .54 | 2.63% |
| 2 | 8.17±3.08 | .85±.05 | .56 | 2.56% |
| 3 | 7.83±3.03 | .85±.05 | .57 | 2.53% |
| 4 | -6.50±3.10 | 1.05±.03 | .84 | 5.18 kg |
| 5 | -4.98±3.03 | 1.04±.03 | .84 | 5.14 kg |
| Carcass | | | | |
| 6 | 9.21±2.55 | .83±.04 | .64 | 2.31% |
| 7 | 8.96±2.48 | .83±.04 | .66 | 2.26% |
| 8 | -2.13±2.50 | .99±.02 | .88 | 4.45 kg |
| 9 | -2.07±2.46 | .99±.02 | .88 | 4.40 kg |

Table 7. Relationship between actual and predicted percentage of retail product for different categories of retail yield

| Retail yield category | Equation: Live animal | Equation: Carcass | Predicted value, % | Bias, % | Absolute difference, % | Correlation of actual and predicted value |
|---|---|---|---|---|---|---|
| Low (<61%) | 1 | | 62.16 | 3.34 | 3.69 | .40 |
| | 2 | | 61.88 | 3.06 | 3.38 | .41 |
| | 3 | | 61.76 | 2.94 | 3.25 | .42 |
| | | 6 | 61.48 | 2.66 | 3.15 | .47 |
| | | 7 | 61.45 | 2.63 | 3.17 | .48 |
| Medium (61 to 65%) | 1 | | 65.43 | 2.38 | 2.59 | .57 |
| | 2 | | 65.14 | 2.07 | 2.42 | .60 |
| | 3 | | 65.04 | 1.99 | 2.34 | .58 |
| | | 6 | 65.08 | 2.03 | 2.36 | .57 |
| | | 7 | 65.06 | 2.00 | 2.35 | .55 |
| High (>65%) | 1 | | 67.72 | -.21 | 1.63 | .59 |
| | 2 | | 67.67 | -.25 | 1.63 | .60 |
| | 3 | | 67.63 | -.29 | 1.64 | .61 |
| | | 6 | 68.21 | .29 | 1.46 | .72 |
| | | 7 | 68.37 | .45 | 1.51 | .72 |

Table 8. Relationship between actual and predicted weight of retail product for different categories of retail yield

| Retail yield category | Equation: Live animal | Equation: Carcass | Predicted value, kg | Bias, kg | Absolute difference, kg | Correlation of actual and predicted value |
|---|---|---|---|---|---|---|
| Low (<98 kg) | 4 | | 94.86 | 4.08 | 4.82 | .74 |
| | 5 | | 94.44 | 3.66 | 4.56 | .76 |
| | | 8 | 95.85 | 5.07 | 5.29 | .71 |
| | | 9 | 95.79 | 5.00 | 5.22 | .72 |
| Medium (98 to 111 kg) | 4 | | 106.49 | 2.22 | 4.75 | .40 |
| | 5 | | 106.08 | 1.81 | 3.86 | .42 |
| | | 8 | 107.17 | 2.90 | 4.05 | .58 |
| | | 9 | 107.39 | 3.12 | 4.26 | .59 |
| High (>111 kg) | 4 | | 117.94 | -1.89 | 4.21 | .80 |
| | 5 | | 117.63 | -2.20 | 4.46 | .81 |
| | | 8 | 121.63 | 1.79 | 3.41 | .87 |
| | | 9 | 121.58 | 1.75 | 3.25 | .87 |

## APPENDIX

In addition to the totally trimmed (0 cm fat thickness) endpoint. retail product weight and percentage were calculated at a closely trimmed (.76 cm fat thickness). boneless endpoint. This endpoint represents the fat trim level many processors have made available in recent years for boxed beef. due to demands for leaner. more consistent product. At this time. sale of totally trimmed (0 cm fat thickness) product has not been widely adopted by the industry. although many academic institutions have used this fat trim level in research studies. In the future. it is likely that more packers will adopt totally trimmed product. as less fabrication will be done by retailers and more product will leave the packing plant as case-ready. This appendix contains additional analyses conducted for closely trimmed (.76 cm fat thickness) PRPRD and KGRPRD. Additionally. the use of a visual muscle score to predict retail product was evaluated.

### Prediction Equations for Closely Trimmed Retail Product

At the closely trimmed endpoint. retail product weight and percentage averaged 112.2 kg (SD = 13.5) and 69.5% (SD = 3.7). respectively. As a result of more external fat being left on the various retail cuts. retail product weights and percentages were higher for the closely trimmed than totally trimmed endpoint (103.5 kg and 64.2%).

Table A.1 contains simple correlation coefficients between carcass and live animal traits with weight and percentage of closely trimmed retail product. These correlations are similar to those reported for totally trimmed retail product. However.

measurements of 12-13th rib fat (UFAT and ACFAT) were not significantly ($P > .10$) correlated with closely trimmed KGRPRD. These same variables had small, negative relationships with totally trimmed KGRPRD. Alternative ultrasound fat measurements of URPFAT and UBDWALL had weak, positive correlations with closely trimmed KGRPRD. These relationships are likely the result of heavier animals having more fat cover, and also more retail product weight. Weight variables (FWT and HCW) had slightly stronger correlations with both KGRPRD and PRPRD at the closely trimmed vs. totally trimmed endpoint.

Prediction equations for closely trimmed PRPRD and KGRPRD using live animal measures are reported in Table A.2. Variables included in final models and their order of inclusion using stepwise regression analysis were not different for closely trimmed vs. totally trimmed retail product. Coefficients of determination were slightly lower for PRPRD at the closely trimmed endpoint ($R^2 = .57$ to .60) than totally trimmed endpoint ($R^2 = .58$ to .61). When used as a single predictor, UFAT accounted for more variation in PRPRD for totally trimmed vs. closely trimmed ($R^2 = .54$ vs. .53). These differences may simply be due to fabrication, as precise fat trim removal is more difficult at .76 vs. 0 cm. However, for KGRPRD, $R^2$ values for closely trimmed exceeded those of totally trimmed (.86 vs. .84 for final models). This difference can be attributed to FWT. When used alone as a single predictor, FWT resulted in $R^2$ values of .74 and .66 for closely trimmed and totally trimmed retail product, respectively. Since FWT includes both fat and lean, as more fat is left on retail cuts the relationship between FWT and KGRPRD becomes stronger. Herring et al. (1994) also found $R^2$ values for retail product weight to increase as fat trim level increased. In the present study, RMSE decreased for both KGRPRD and PRPRD in closely trimmed vs. totally trimmed retail product. This is in agreement with Hamlin et al. (1995) who reported lower residual standard deviations for live animal equations predicting percentage of retail product at .76 vs. 0 cm fat trim.

Presented in Table A.3 are prediction equations for closely trimmed PRPRD and KGRPRD using carcass traits as independent variables. As with the live animal equations, models using carcass traits for predicting closely trimmed retail product were similar to those for totally trimmed retail product. Less variation in PRPRD was explained at .76 vs. 0 cm fat trim level for PRPRD, whereas $R^2$ values for closely trimmed KGRPRD exceeded those reported for totally trimmed KGRPRD.

### Accuracy of Predicting Closely Trimmed Retail Product

Prediction equations were also developed from 1993-born steers for closely trimmed (.76 cm fat thickness) PRPRD and KGRPRD and evaluated for accuracy when applied to the 1995 calf crop. Means for closely trimmed PRPRD were higher ($P < .01$) for steers born in 1993 (70.4±3.8%) than 1994 (68.8±3.4%), whereas closely trimmed KGRPRD was higher ($P < .01$) for 1994 steers (113.6±13.5 vs. 111.0±13.3). These differences can be attributed to the steers having more fat cover and being heavier in 1994 than in 1993.

Regression equations for predicting closely trimmed PRPRD and KGRPRD developed from live animal measurements are presented in Table A.4. Results are similar to equations previously reported for totally trimmed (0 cm fat thickness) retail product. Most of the variation in PRPRD was explained by UFAT ($R^2$ = .58 alone), and both URPFAT and UBDWALL were significant ($P < .10$) variables included in the final model (Equation C). Final live weight accounted for 70% of the variation in closely trimmed KGRPRD, with UFAT, UREA, and URPFAT accounting for the remaining 15% for Equation E.

Corresponding equations derived from carcass measurements are presented in Table A.5. Equations F and H use yield grade traits as predictor variables, whereas Equations G and I also include MARB. The addition of MARB to yield grade variables resulted in an increase in $R^2$ value of .04 and .01 for closely trimmed PRPRD and KGRPRD, respectively. Consistent with what was reported for totally trimmed retail product, carcass trait equations explained 5% more of the variation in both closely trimmed PRPRD and KGRPRD than live animal equations. As stated previously, these differences can be partially attributed to animal variation in dressing percentage and the use of FWT vs. HCW in live animal equations.

Table A.6 reports the mean closely trimmed PRPRD predicted by the various equations when applied to the 1994 steers. All equations overestimated ($P < .01$) actual closely trimmed PRPRD and KGRPRD. Means for bias and absolute residual were not different ($P > .10$) between Equations C and F as well as C and G, suggesting that the best live animal model (Equation C) was as accurate as carcass equations for predicting closely trimmed PRPRD. Correlations between actual and predicted PRPRD ranged from .73 to .75 for live animal equations, and from .79 to .81 for carcass equations.

For closely trimmed KGRPRD, all equations also overestimated ($P < .01$) actual KGRPRD. Mean bias for Equation E was lower ($P < .01$) than for Equations H and I, indicating that the predicted KGRPRD mean for the best live animal equation was closest to the actual KGRPRD mean. Correlations between actual and predicted KGRPRD were similar for all models (Table A.6).

Regression of predicted values on actual values for closely trimmed retail product equations are presented in Table A.7. Live animal and carcass equations exhibit a similar fit for PRPRD, although carcass equations explained an additional 9% of the variation in actual PRPRD. Similar results were obtained for totally trimmed PRPRD. Carcass equations for closely trimmed KGRPRD exhibited intercepts close to zero and slopes of one. Live animal equations accounted for 87% of the variation in actual KGRPRD, and carcass equations accounted for 90 and 91%. The lower RMSE and better model fit for carcass vs. live animal KGRPRD equations are likely due to using HCW rather than FWT as a predictor.

The addition of alternative ultrasound fat measurements (URPFAT and UBDWALL) to UFAT, UREA, and FWT improved the precision of live animal equations for prediction of closely trimmed PRPRD and KGRPRD.

**The Use of Visual Muscle Score as a Predictor of Beef Carcass Retail Product**

In addition to the live animal variables previously discussed, visual muscle scores (VMSC) were also assessed. Immediately following ultrasound image collection, each steer was scored using a scale of 1 = light muscled to 9 = heavy muscled (Long, 1970) by three experienced, trained evaluators. Scores were a subjective estimate of total muscle mass, independent of weight and fat cover. The most frequent score was used for prediction model development.

Mean VMSC for the entire population was 4.5 (SD = 1.4), with a range of 2 to 9. Reported in Table A.8 are least squares means and standard errors for VMSC by sire breed group. Belgian Blue-sired steers had higher ($P < .01$) VMSC than other sire breed groups, while Angus and Hereford-sired steers had higher ($P < .01$) VMSC than Brahman, Boran, and Tuli-sired steers. However, there was little variation within a sire breed group for VMSC as standard deviations ranged from .80 to .94.

Simple correlation coefficients calculated across all sire breed groups between VMSC with totally trimmed PRPRD and KGRPRD were .35 and .57, respectively. However, when breed effects were removed, the partial correlation coefficient between VMSC and totally trimmed PRPRD was nonsignificant ($P > .10$). The addition of VMSC to final models for totally trimmed PRPRD and KGRPRD increased $R^2$ values .04 and .02. However, when breed effects were fit using stepwise regression analysis, VMSC was the last variable to enter models for both totally trimmed PRPRD and KGRPRD, and explained < 1% additional variation after other live animal variables and breed effects had been included. Comparatively, inclusion of breed effects increased $R^2$ values of final models using live animal variables .09 and .04 for totally trimmed PRPRD and KGRPRD, respectively.

Due to lack of variation within a breed group and the absence of a strong relationship between VMSC and retail product when breed effects were removed, VMSC was not included in final model development. Additionally, the precision and repeatability of VMSC may be questionable due to its subjectivity. Researchers have found subjective measurements of carcass muscling have little value in estimating cutability. In agreement with the findings of the present study, Herring et al. (1994) assigned visual muscle scores ranging from 1 to 10 (mean = 4.6, SD = 1.1) to a group of 44 Hereford crossbred steers and reported visual muscle scores to not be useful predictors of retail product.

Table A.1. Simple correlations of traits with weight and percentage of closely trimmed retail product

| Trait | KGRPRD | PRPRD |
|---|---|---|
| FWT | .86*** | -.29*** |
| UFAT | -.02 | -.73*** |
| UREA | .60*** | .15*** |
| URPFAT | .10* | -.66*** |
| UBDWALL | .17*** | -.48*** |
| HT | .65*** | -.12** |
| HCW | .88*** | -.28*** |
| Unadjusted fat thickness | -.01 | -.67*** |
| ACFAT | -.05 | -.72*** |
| CREA | .66*** | .29*** |
| CKPH | .09* | -.42*** |
| USDA yield grade | .02 | -.79*** |
| MARB | .01 | -.53*** |

*Values different from zero ($P < .05$).

**Values different from zero ($P < .01$).

***Values different from zero ($P < .001$).

Table A.2. Equations for predicting weight and percentage of closely trimmed retail product from live animal measurements

| Dependent variable and equation | $R^2$ | RMSE | Cp | Partial regression coefficients: Intercept | UFAT, cm | URPFAT, cm | UREA, $cm^2$ | UBDWALL, cm | FWT, kg |
|---|---|---|---|---|---|---|---|---|---|
| PRPRD | | | | | | | | | |
| 17 | .57 | 2.44 | 37.93 | 78.87 | -5.527 | -3.366 | | | |
| 18 | .58 | 2.41 | 26.47 | 74.90 | -5.371 | -3.346 | .050 | | |
| 19 | .55 | 2.49 | 59.90 | 75.75 | -7.034 | | .081 | | -.010 |
| 20 | .59 | 2.38 | 13.67 | 75.79 | -4.535 | -3.380 | .069 | -.632 | |
| 21 | .60 | 2.36 | 6.00 | 76.86 | -4.419 | -2.987 | .092 | -.631 | -.006 |
| KGRPRD | | | | | | | | | |
| 22 | .82 | 5.75 | 166.21 | 13.03 | -11.432 | | | | .200 |
| 23 | .86 | 5.10 | 18.37 | -7.40 | -9.397 | | .400 | | .176 |
| 24 | .86 | 5.02 | 4.10 | -7.10 | -7.072 | -4.002 | .389 | | .181 |

Table A.3. Equations for predicting weight and percentage of closely trimmed retail product from carcass measurements

| Dependent variable and equation | $R^2$ | RMSE | Cp | Partial regression coefficients | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Intercept | ACFAT, cm | CKPH, cm | CREA, $cm^2$ | HCW, kg | MARB |
| PRPRD | | | | | | | | | |
| 25 | .57 | 2.45 | 169.11 | 79.34 | -5.748 | -1.348 | | | |
| 26 | .60 | 2.34 | 109.39 | 72.79 | -5.345 | -1.544 | .086 | | |
| 27 | .64 | 2.23 | 52.99 | 74.39 | -4.602 | -1.359 | .146 | -.022 | |
| 28 | .67 | 2.14 | 6.00 | 79.30 | -4.076 | -1.253 | .130 | -.018 | -.012 |
| KGRPRD | | | | | | | | | |
| 29 | .86 | 5.03 | 176.08 | 16.21 | -9.892 | | | .309 | |
| 30 | .88 | 4.66 | 77.14 | 4.52 | -7.918 | | .276 | .275 | |
| 31 | .89 | 4.49 | 33.00 | 7.75 | -7.101 | -2.252 | .284 | .281 | |
| 32 | .90 | 4.37 | 6.00 | 15.49 | -6.272 | -2.084 | .260 | .287 | -.019 |

Table A.4. Live animal prediction equations for weight and percentage of closely trimmed retail product developed from 1994 data

| | | | | Partial regression coefficients | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dependent variable and equation | $R^2$ | RMSE | Cp | Intercept | UFAT, cm | URPFAT, cm | UREA, $cm^2$ | FWT, kg | UBDWALL, kg |
| PRPRD | | | | | | | | | |
| A | .63 | 2.32 | 23.37 | 74.74 | -7.253 | | .121 | -.011 | |
| B | .65 | 2.26 | 7.70 | 75.07 | -5.850 | -2.561 | .109 | -.008 | |
| C | .65 | 2.25 | 6.00 | 75.96 | -5.179 | -2.543 | .122 | -.009 | -.467 |
| KGRPRD | | | | | | | | | |
| D | .85 | 5.21 | 13.20 | -6.47 | -9.286 | | .453 | .168 | |
| E | .85 | 5.12 | 4.24 | -5.88 | -6.764 | -4.602 | .432 | .174 | |

Table A.5. Carcass prediction equations for weight and percentage of closely trimmed retail product developed from 1994 data

| Dependent variable and equation | $R^2$ | RMSE | Cp | Partial regression coefficients: Intercept | ACFAT, cm | CREA, $cm^2$ | HCW, kg | CKPH, % | MARB |
|---|---|---|---|---|---|---|---|---|---|
| PRPRD | | | | | | | | | |
| F | .68 | 2.17 | 42.10 | 72.08 | -5.098 | .182 | -.024 | -.860 | |
| G | .72 | 2.04 | 6.00 | 77.93 | -4.570 | .156 | -.019 | -.678 | -.014 |
| KGRPRD | | | | | | | | | |
| H | .89 | 4.35 | 27.81 | 4.59 | -7.585 | .322 | .281 | -1.577 | |
| I | .90 | 4.18 | 6.00 | 14.07 | -6.729 | .280 | .290 | -1.283 | -.022 |

Table A.6. Validation statistics for closely trimmed retail product equations

| Equation | Predicted value | Bias[a] | Absolute residual | Correlation of actual and predicted value[a] |
|---|---|---|---|---|
| Live animal | | | | |
| A | 70.33% | 1.76% | 2.38% | .73 |
| B | 70.14% | 1.57% | 2.25% | .74 |
| C | 70.07% | 1.50% | 2.19% | .75 |
| D | 114.74 kg | 1.12 kg | 4.08 kg | .93 |
| E | 114.39 kg | .78 kg | 4.06 kg | .93 |
| Carcass | | | | |
| F | 70.09% | 1.52% | 2.06% | .79 |
| G | 70.11% | 1.54% | 2.06% | .81 |
| H | 116.55 kg | 2.93 kg | 3.86 kg | .95 |
| I | 116.58 kg | 2.97 kg | 3.86 kg | .95 |

[a]Values different from zero ($P < .01$).

Table A.7. Regression of predicted values on actual values for closely trimmed retail product equations

| Equation | Intercept | $b_1$ | $R^2$ | RMSE |
|---|---|---|---|---|
| Live animal | | | | |
| A | 9.56±3.55 | .84±.05 | .53 | 2.33% |
| B | 9.67±3.38 | .84±.05 | .55 | 2.27% |
| C | 9.27±3.32 | .85±.05 | .56 | 2.24% |
| D | -7.57±3.00 | 1.06±.03 | .87 | 4.93 kg |
| E | -6.19±2.97 | 1.05±.03 | .87 | 4.92 kg |
| Carcass | | | | |
| F | 10.75±2.80 | .83±.04 | .63 | 2.05% |
| G | 10.07±2.69 | .83±.04 | .65 | 1.99% |
| H | -3.13±2.43 | 1.00±.02 | .90 | 4.22 kg |
| I | -3.16±2.39 | 1.00±.02 | .91 | 4.15 kg |

Table A.8. Least squares means and standard errors of visual muscle scores for sire breed groups

| Sire breed group | n | Visual muscle score |
|---|---|---|
| Hereford | 86 | $4.53 \pm .11^{b}$ |
| Angus | 82 | $4.70 \pm .11^{b}$ |
| Brahman | 76 | $3.62 \pm .11^{cd}$ |
| Boran | 93 | $3.42 \pm .10^{d}$ |
| Tuli | 96 | $3.73 \pm .09^{c}$ |
| Belgian Blue | 101 | $6.41 \pm .09^{a}$ |

[a,b,c,d]Means between breed groups are different ($P < .01$).

## GENERAL SUMMARY

Results from this study and the literature referenced indicate a strong relationship between real-time ultrasound and carcass measurements for fat cover and longissimus muscle area in beef cattle. Proficiency levels attainable by highly-skilled, experienced technicians suggest that ultrasound can consistently predict differences between breeding animals for carcass traits, and accurately characterize composition in feedlot cattle for market determination. Establishment of a quality control data collection system that would minimize ultrasound inaccuracies caused by technician and machine would greatly enhance the application of this technology to the industry.

This project also demonstrated that live animal equations based on real-time ultrasound measurements are useful predictors of carcass retail yield and weight of saleable product in market cattle. The similarity in the precision of live animal and carcass-derived equations indicate another potential use for ultrasound in beef improvement programs. Models developed from live animal measurements had a higher level of predictability for weight than percentage of retail product. However, because live weight drives these equations, selection for retail product weight would likely result in an increase in size and not an improvement in composition through increased muscularity or decreased fat cover. Therefore, percentage retail product should be used as the means to improve end product. Due to differences in fat measurements between seedstock and feedlot animals, the application of live animal ultrasound prediction models for retail yield in breeding cattle needs to be investigated.

The alternative ultrasound measurements of rump fat and body wall thickness proved to be important additional variables to 12-13th rib fat and longissimus muscle area in describing carcass composition. Additional research seems warranted to further define the body wall thickness measurement. Identification of additional indicators of muscle mass that could be measured with ultrasound in an accurate, repeatable manner may also improve live animal prediction of body composition. Such measurements would be especially useful in breeding and slaughter cattle that have less variation in fat cover than the population utilized in this study.

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